ELECTRIC POWER STATIONS

BY

L. W. W. MORROW, M. E.
Fellow A. I. E. E., Member A. S. M. E.

First Edition
Third Impression

McGRAW-HILL BOOK COMPANY, Inc.
NEW YORK AND LONDON
1927

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

INTRODUCTION

The production, transmission and distribution of electrical energy on a large scale in an adequate and economical manner is an engineering task of the first magnitude. Each system has its specific details and problems the solutions of which depend largely upon local conditions, but there are certain fundamental engineering and economic principles that apply to all systems.

Different men may have charge of the several activities of a power organization, depending upon the size of the system, but the executive head of the utility must be a man with fundamental knowledge of all the engineering and economic aspects of the operations in order that he may make decisions intelligently.

In the power plant, engineers must deal with problems of design and construction of buildings, the installation and operation of machines and equipment, the records of operation and the internal organization and operation of the plant for efficiently utilizing every dollar invested.

The transmission of the energy involves a whole mass of engineering work in construction, operation and organization. And in the distribution and sale of the energy a still more complex engineering and economic problem is encountered. Beyond all these elements lies the realm of human relationships and the obligations inherent in public utility operations.

Considered as separate details, energy production, transmission and distribution each affords opportunity for specialization and study, but a broader perspective of the field leads to the conclusion that all the detail and the equipment are subordinated to one objective. And this objective is to produce, transmit and distribute the stream of electrical energy in an efficient and economical manner. Thus the problem for the executive and the engineer is a problem of selection of existing equipment and its assemblage at the different locations along the energy stream. Viewed in this light, an attempt is made in the following pages to outline guiding principles as exemplified by the best prac-

tices and opinions of today. In the study it will be shown *that basic engineering principles—civil, electrical, chemical* and mechanical—are the only true guides, but that costs and relative values are determining elements in their application.

Thus an attempt is made to coordinate different engineering principles and a large variety of engineering equipment and to weigh the respective elements in relation to the development of an efficient and economical system. An attempt is made to give training in engineering and executive duties connected with utility operation. This training presupposes a fundamental knowledge of the types of power plant, transmission and distribution equipment as regards its operating principles and construction details and these pages accent those elements to be considered in utilizing this equipment to the best advantage.

L. W. W. M.

New York, N. Y.
December, 1926.

CONTENTS

ELECTRIC POWER STATIONS

CHAPTER I

POWER IN NATIONAL LIFE

The United States stands in the front rank of the nations in point of material accomplishment and social well-being and this position has been attained very largely through its great use of power. Conditions in this country support the statement that the prosperity and commercial position of a nation can be measured by its per capita use of power.

In a few years the electric power plant has become the accepted agency for the production of power on a wholesale scale, because electricity possesses tremendous advantages over other known energy forms and these advantages can be economically realized under existing conditions. The growth of the electrical system has been so rapid and so general that a national power system lies in the near future. In such a system a network of transmission lines and large power stations will make possible reliable, abundant and cheap power in all localities and thus react on the whole economic and social fabric of the nation. Even now engineering skill and equipment can bring such a system into existence, but there are political, social and economic questions that offer handicaps to its immediate realization.

And this great power development is indeed marvelous, for only a few years have been passed since electricity first became available as a power source. In 1882 Thomas A. Edison installed the Pearl Street central station and supplied a few customers with direct current by means of wires placed underground in galvanized-iron pipes which were filled with an insulating compound. The lamps then used 6.5 watts per candlepower and the generating equipment was small and inefficient. In 1888 there were 410 electrical stations in this country and 70 per cent of these furnished service at night only. In 1886 the first alternating-current system was installed at Greensburg, Pennsylvania, and transformers were used for the first time.

Yet in 1890 the lamps were improved so they used 3.1 watts per candlepower; the Edison three-wire system came into being with its saving of 66 per cent in copper and the slow-speed direct-

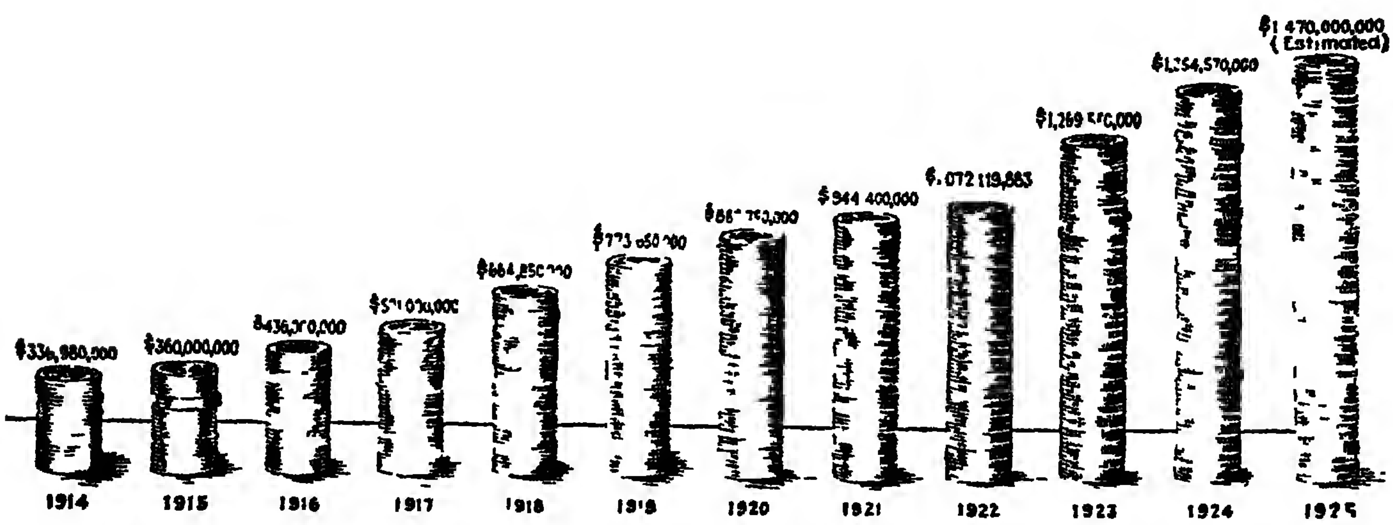

Fig. 1.—Gross revenue from sale of electrical energy.

connected engine generator became a commercial prime mover. In 1896 high-tension transmission lines with rotary converter substations were first used and the number of electric utilities

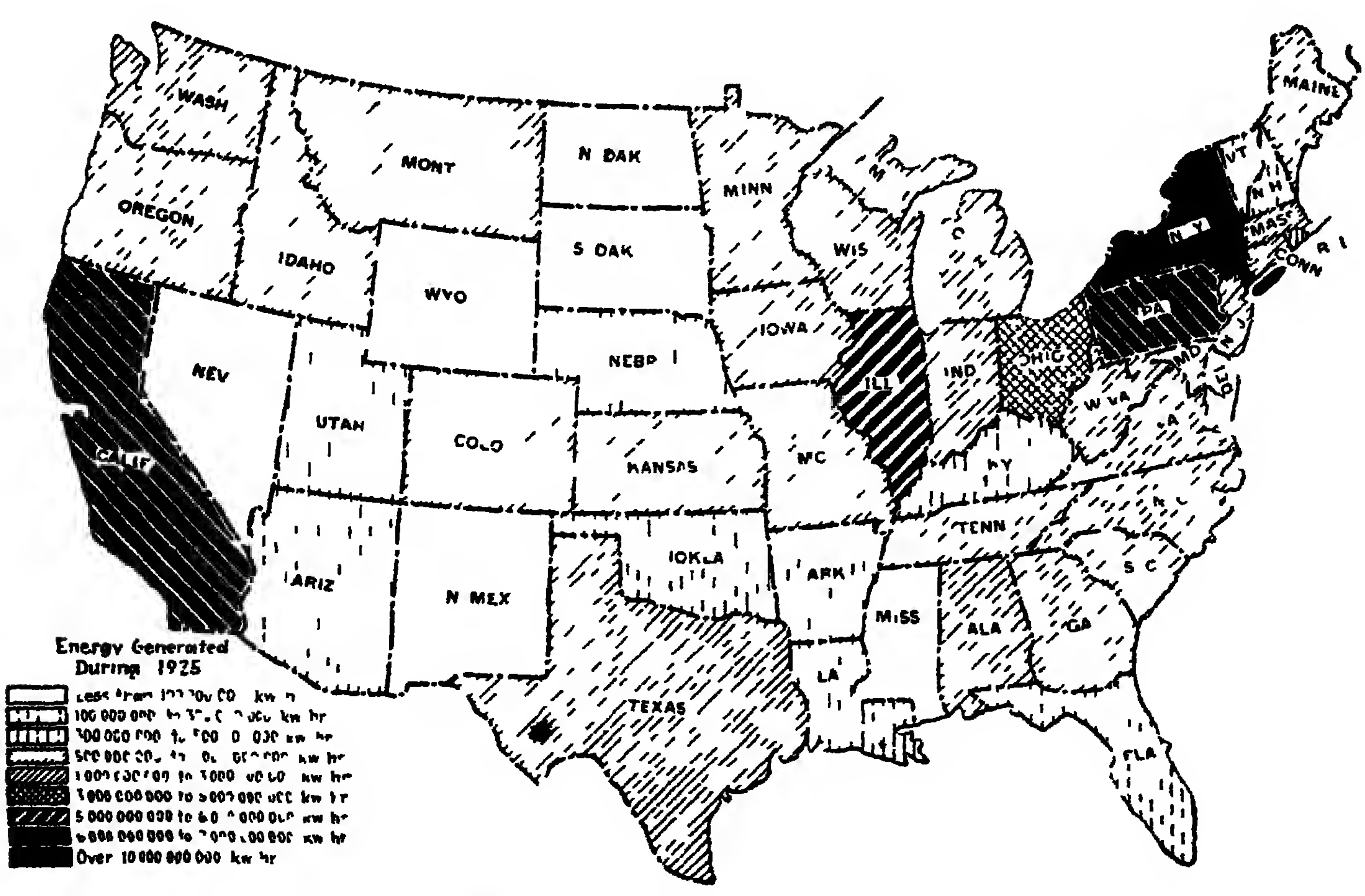

Fig. 2.—Energy output of central stations by states.

grew rapidly. During the past 30 years the demand for electric power has been so great that the output of the stations doubled about every 6 years and all present indications point to a continuation of this demand. Figure 4 shows the rate of increase.

Present Status of Power.—The 5,250 light and power systems in this country, with a generator rating of 27,000,000 kva., generated in 1925 more than 59,000,000,000 kw.-hr. of electrical energy which produced a gross revenue of about $1,500,000,000. This production compares very favorably with that of all the other nations of the world, as is indicated by the figures of Table II. In addition, over 250,000 manufacturing establishments in this country have an aggregate installed capacity of over 33,000,000 hp. in prime movers which very largely produce electrical energy for factory use. In this connection it is estimated that the central stations supply about 58 per cent of the energy used in the industrial plants and mines.

TABLE I.—PER CAPITA CONSUMPTION OF ELECTRICAL ENERGY—1924

	Kilowatt-hours
Canada	878
Switzerland	765
United States	600
Norway	520
Sweden	400
Germany	220
Great Britain	180
France	160

TABLE II.—WORLD CONSUMPTION OF ELECTRICAL ENERGY—1924

	Kilowatt-hours
United States	65,800,000,000
Germany	13,600,000,000
Japan	10,000,000,000
Canada	8,125,000,000
Great Britain	7,400,000,000
France	6,400,000,000
Italy	5,400,000,000
Switzerland	2,900,000,000
Sweden	2,340,000,000
Norway	1,630,000,000

The electrical systems in the United States in 1925 supplied 14,530,000 lighting customers in residences, 2,800,000 commercial lighting customers and over 620,000 power customers and filled the demand for power by all kinds of industry, including manufacturing, mining, agriculture, electro-chemical and transportation. And with over $6,000,000,000 invested in power stations,

Table III.[1]—Load and Output for the 50 Largest Light and Power Systems in the United States—1926

Company	Rank in 1925	1925				
		Peak load, kilowatts (instantaneous)	Peak load (estimated over 30-min. period), kilowatts	Date of instantaneous peak	Output for year, kilowatt-hours	Average load in kilowatts, 1925
(2)	(3)	(4)	(5)	(6)	(7)	(8)
Niagara Falls Power Company	1	....	437,016	Dec. 26	3,161,130,010	360,860
Commonwealth Edison Company	2	809,000	792,000	Dec. 23	3,091,424,000	353,000
Edison-United Companies, New York	3	656,312	642,907	Dec. 21	2,262,620,409	258,290
Pacific Gas and Electric Company	4	380,084	....	Nov. 4	2,001,474,640	228,479
Southern California Edison Company	5	395,900	....	July 22	1,987,661,654	226,902
Detroit Edison Company	6	390,100	389,100	Oct. 2	1,732,420,700	197,800
Philadelphia Electric Company System	7	387,200	361,600	Dec. 10	1,521,639,979	173,815
Public Service Electric and Gas Company	8	367,048	353,000	Dec. 9	1,358,318,172	155,400
Montana Power Company	9	172,600	168,900	Aug 14	1,234,052,127	140,485
Duquesne Light Company	10	271,200	264,900	Dec. 16	1,230,292,597	140,200
North American Company (Missouri, Illinois and Iowa)	11	258,623	....	Dec. 15	1,200,506,087	137,200
Southeastern Power and Light Company's System	12	291,000	284,000	Oct. 22	1,196,244,494	136,520
Southern Power Company	13	....	297,705	Jan. 12	1,187,872,330	135,600
West Penn System	14	....	209,720	Dec. 22	1,090,203,588	124,452
Cleveland Electric Illuminating Company	15	251,375	247,000	Dec. 17	989,409,700	113,000
Ohio Power Company	16	....	181,600	Dec. 22	890,509,813	101,700
Niagara, Lockport and Ontario Power Company	17	....	172,000	(n)....	872,402,171	99,700
Buffalo General Electric Company	18	191,000	188,800	Dec. 8	869 317,170	99,200
North American Company (Wisconsin System)	19	203,904	....	Dec. 4	849,064,272	97,100
Mohawk Hudson Power Corporation System	20	....	171,100	Nov. 24	809,964,028	92,460
Brooklyn Edison Company	21	228,000	223,850	Dec. 17	783,019,562	89,386
Utah Power and Light Company	22	112,343	....	Dec.	744,186,000	84,952
Northern States Power Company	23	168,659	160,200	Dec. 2	742,601,203	84,800
Consolidated Gas Electric Light and Power Company of Baltimore	24	....	160,700	Dec. 21	718,195,433	81,986
Pennsylvania Power & Light Company	25	130,403	....	Dec.	707,995,258	80,821
Consumers Power Company	26	157,332	155,890	Sept. 15	686,548,440	78,530
New England Power Company	27	....	165,200	Jan. 20	681,696,046	77,850
Tennessee Electric Power Company	28	155,000	142,300	Dec. 11	654,488,668	74,713
Edison Electric Illuminating Company of Boston	29	203,199	....	Dec. 1	648,078,358	74,100
Great Western Power Company	30	122,950	....	Mar. 6	633,357,021	72,054

[1] *Electrical World*, Supplement, Apr. 24, 1926.

TABLE III.[1]—LOAD AND OUTPUT FOR THE 50 LARGEST LIGHT AND POWER SYSTEMS IN THE UNITED STATES—1926.—(*Continued*)

Company (2)	Rank in 1925 (3)	1925 Peak load, kilowatts (instantaneous) (4)	Peak load (estimated over 30-min. period), kilowatts (5)	Date of instantaneous peak (6)	Output for year, kilowatt-hours (7)	Average load in kilowatts, 1925 (8)
Puget Sound Power and Light Company	31	131,468	130,000	Dec. 10	632,626,358	72,000
Public Service Company of Northern Illinois	32	166,390	165,484	Dec. 9	615,092,925	70,216
Union Gas and Electric Company	33	....	145,000	....	562,408,247	64,223
San Joaquin Light and Power Corp.	34	111,890	111,000	July 16	554,614,141	63,312
Ohio Public Service Company	35	106,100	....	Dec. 2	522,063,648	59,600
Washington Water Power Company	36	107,030	98,655	Oct. 30	515,523,750	58,849
Pennsylvania Water and Power Company	37	115,000	110,100	Nov. 13	513,962,900	58,700
Los Angeles, Bureau of Power and Light	38	109,860	109,200	Dec. 16	479,878,822	54,781
Georgia Railway and Power Company	39	120,000	109,000	Dec. 2	435,441,973	49,700
Portland Electric Power Company	40	....	105,500	Dec. 18	421,155,600	48,000
Pennsylvania-Ohio Power and Light Company	41	100,000	94,000	....	417,368,862	47,700
Metropolitan Edison System	42	87,000	84,000	Dec. 1	366,726,210	41,800
Minnesota Power and Light Company	43	75,484	....	Oct.	364,574,445	41,618
Toledo Edison Company	44	81,500	79,400	Oct. 21	350,518,281	42,500
Penn Public Service System	45	84,765	76,885	Dec. 22	341,630,292	39,000
Kansas City Power and Light Company	46	....	71,000	Dec. 4	339,117,030	40,200
North West Utilities Company	47	....	76,599	....	336,956,523	38,465
Potomac Electric Power Company	48	84,000	81,000	Dec. 16	318,700,406	36,380
Turners Falls Power and Light Company	49	71,800	63,500	July 2	317,772,280	36,280
Virginia Electric and Power Company	50	....	79,440	Dec. 15	304,400,743	34,749

transmission lines and distribution systems, the central-station industry has become the fifth in national importance based on capital invested. Some of the individual companies have an output larger than the total energy used by some of the important nations of the world, as will be seen from Tables II and III, and the industry requires a yearly influx of capital aggregating over $1,000,000,000 in order to care for the increased demands for energy.

Trend in Power Development.—The electrical industry was initiated by the growth of large stations in cities, small stations in

towns and still smaller stations in manufacturing plants. Following this period came a concentration of power production into single large plants and an expansion of the transmission and distribution systems over large territorial areas. Of late years the trend has been toward a still greater concentration of energy production into large stations and an interlinking of the systems located in different localities. This trend is along the line of the

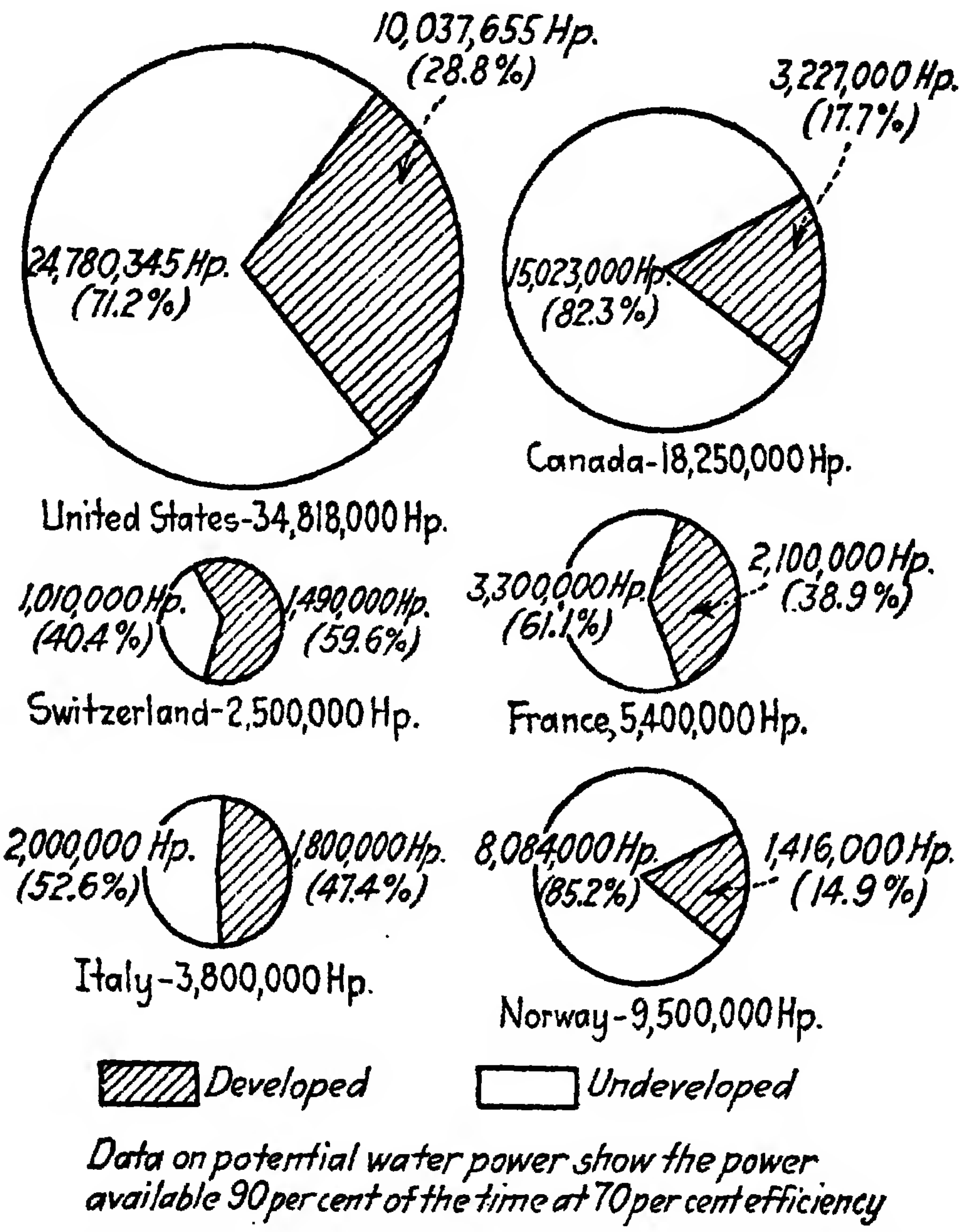

FIG. 3.—Status of water power development in several nations.

superpower systems proposed by W. S. Murray and Frank Baum, and, in fact, in the South, on the Pacific Coast and in the Middle West great superpower systems are already in existence.

There are many reasons for the trend in power development, but the economics of the business is the deciding element. The investment cost per unit of capacity decreases as the size of station increases; hydro-electric stations and carbo-electric stations can be built, located and used most economically through taking advantage of the operations possible through interconnection. A disadvantage, however, is the increased cost of transmission

TABLE IV.—BUDGETS FOR LIGHT AND POWER SYSTEMS[1]

Year	Total central-station construction budgets for year	Total expenditures for electric generating plants	Total expenditures for transmission and distributing systems	Per cent of total spent on generating plants	Per cent of total spent on transmission and distribution systems
1921	$222,408,000	$102,674,000	$119,734,000	46.2	53.8
1922	324,016,000	164,333,000	159,683,000	50.8	49.2
1923	602,143,000	283,813,000	318,330,000	47.1	52.9
1924	692,440,000	379,240,000	313,200,000	54.8	45.2
1925	636,350,000	280,950,000	355,400,000	44.2	55.8
1926	683,890,000	279,140,000	404,750,000	40.8	59.2

[1] *Electrical World*, Jan. 2, 1926.

systems. Interconnection permits the more complete utilization of water powers and watersheds and uses the diversity in time and stream flow to secure economic advantages. Also the load which may be carried is increased because there is diversity in peak loads in different territories because of time or other differences. Less reserve system capacity is needed on interconnected systems and the combined operation of steam and water plants is rendered more economical. Another good reason is that a greater utilization of the investment can be obtained by providing load for new station equipment before the market can absorb it. A new station can transmit its temporary surplus power to another system, or, as industrial conditions change in different localities, the production of power can be more readily controlled. But this change has come about gradually in order to amortize the existing investments.

This trend toward a national power system introduces many problems for solution. National regulation may replace state regulation; national policies, laws, financing and operation will have to be considered and instituted. A mammoth task confronts the leaders in the central-station industry and it is startling to vision the future from the background of the past and note the very rapid growth in demand and changes in the art that are now occurring.

Political Status of the Light and Power Industry.—In the early days, light and power systems were installed and operated

through private enterprise, but through years of development and as they became more and more public necessities a gradual change has occurred. Today there are light and power systems owned and operated by private enterprise but regulated by the Federal government; others of the same type are regulated by

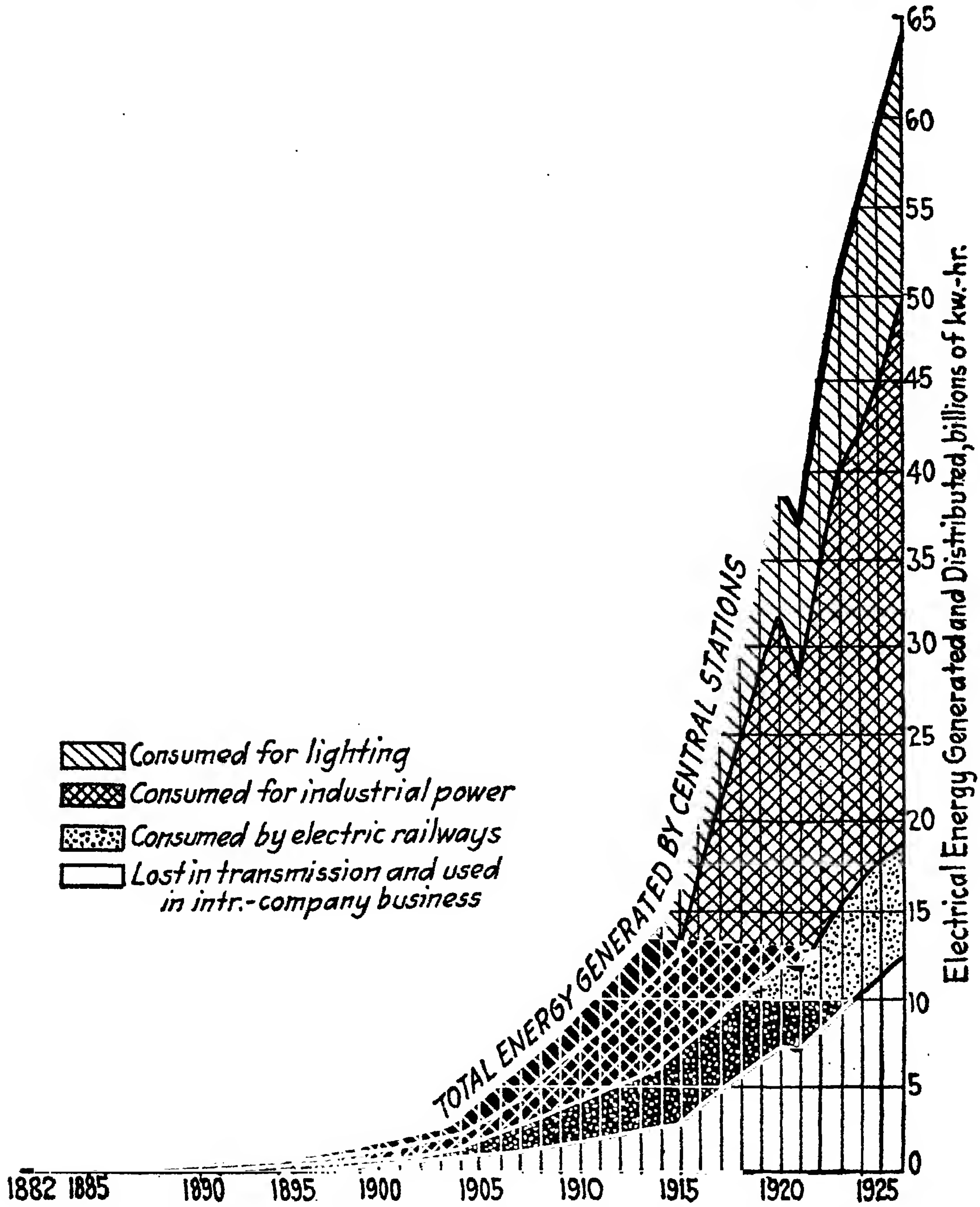

FIG. 4.—No saturation is indicated in the use of electricity.

state or city commissions and still other systems are both owned and operated by states or municipalities. About one-fourth of the total number of systems serving the public are municipal enterprises, but their total output is only a small per cent of the output of the privately owned plants.

The Federal government has had intimate relations with the privately owned light and power systems through one commission. The Federal Power Commission confines its activities to those enterprises involving the development of the water powers

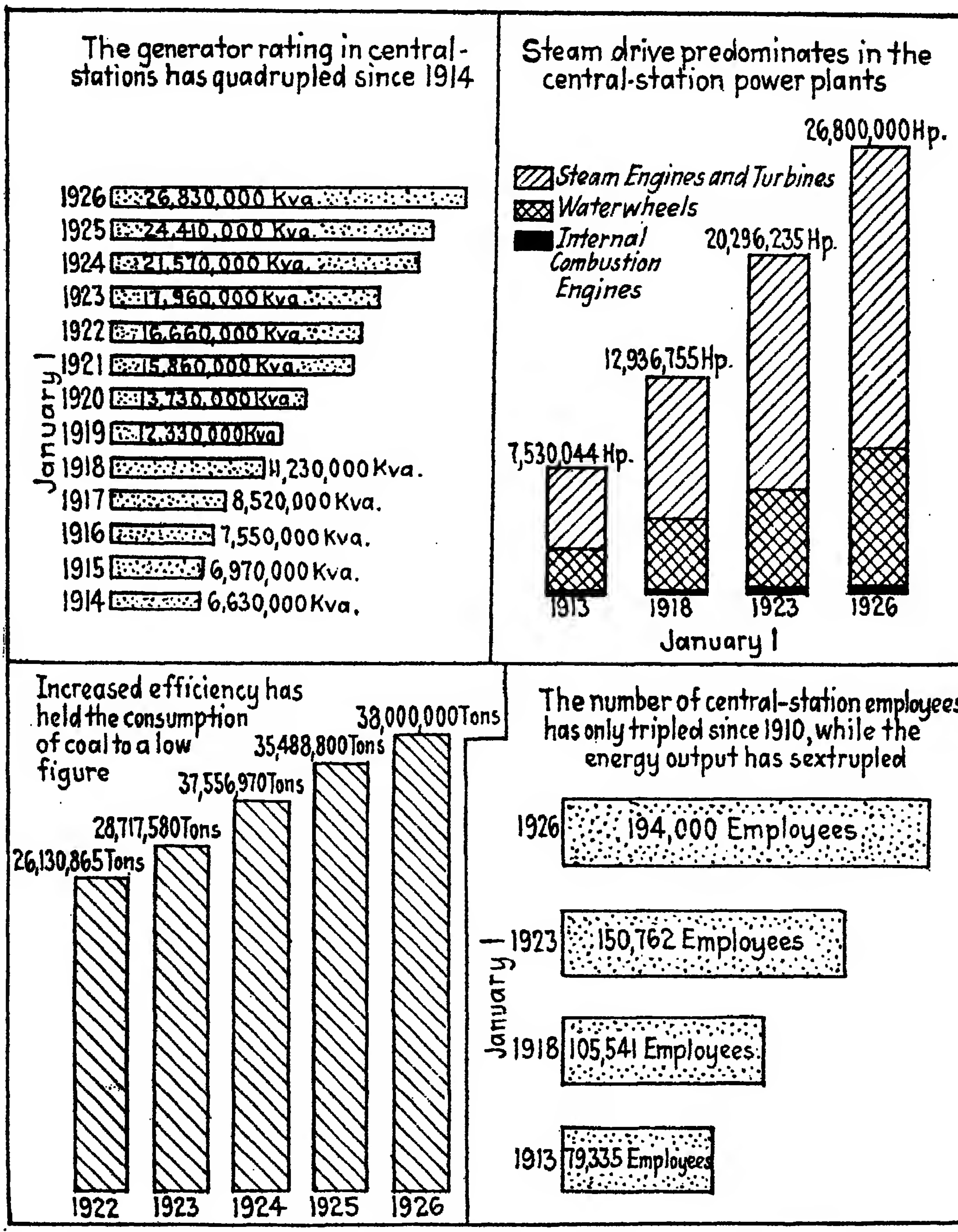

Fig. 5.—Generating capacity, types of drives, fuel used and number of employees in central-station industry.

of the nation in national parks and on navigable streams. It is of recent origin but has carried out broad and constructive plans for the greater utilization of water power. The Interstate Commerce Commission has had little to do with the light and

power companies, but its duties may later involve the regulation of such systems as transmit power across state boundaries.

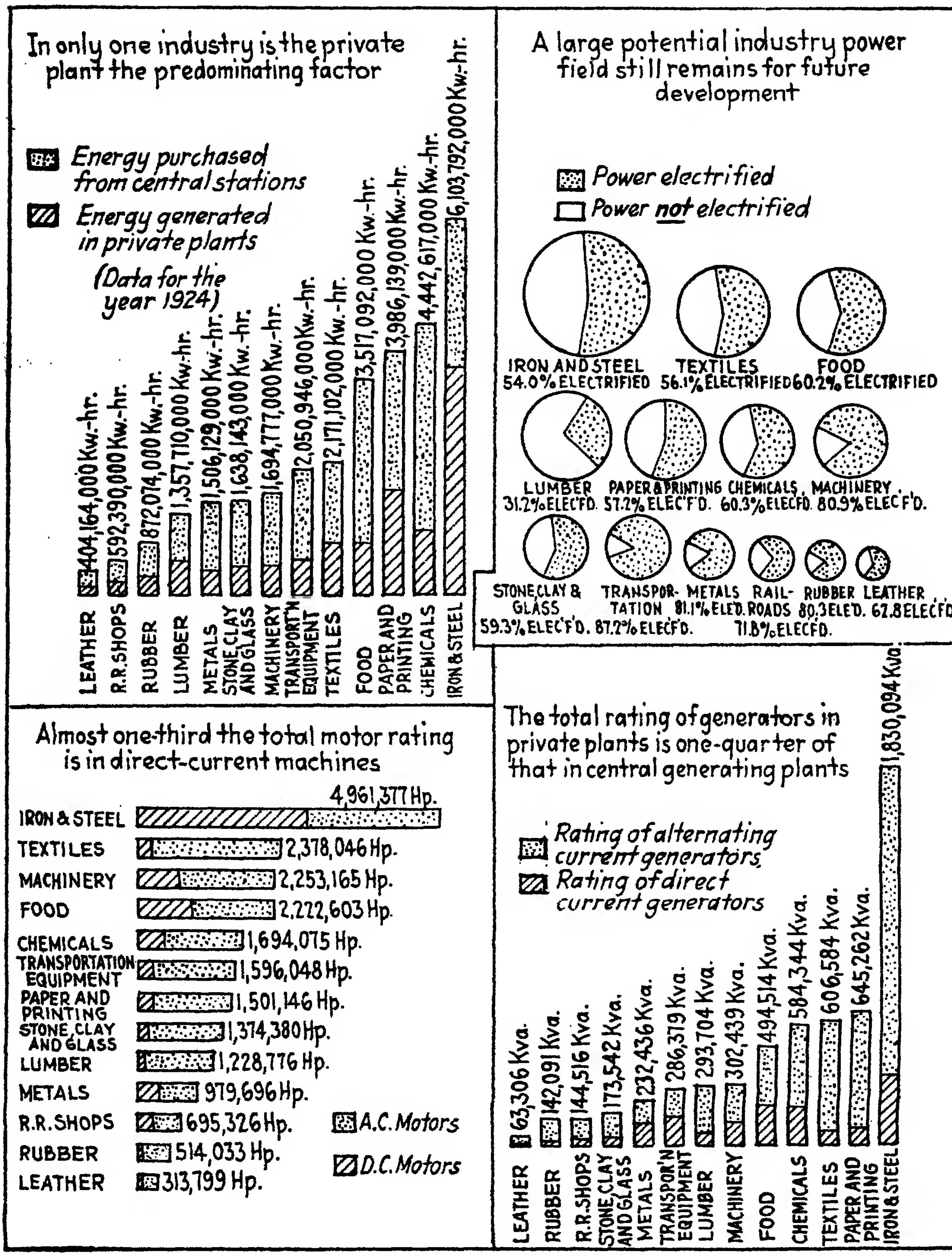

FIG. 6.—Status of electrification in American industry.

Each state has some type of regulatory body to act for the legislature in regulating privately owned utility enterprises. These commissions differ in authority in the several states but, in general, control the rates and financing of the utilities. In

TABLE V.—ENERGY PRODUCTION OF POWER STATIONS IN THE UNITED STATES[1]

Section	Energy generated during 1923				Energy generated during 1924				Energy generated during 1925[a]			
	Hydro-plants		Fuel power plants		Hydro-plants		Fuel power plants		Hydro-plants		Fuel power plants	
	Thousands of kilowatt-hours	Per cent of total	Thousands of kilowatt-hours	Per cent of total	Thousands of kilowatt-hours	Per cent of total	Thousands of kilowatt-hours	Per cent of total	Thousands of kilowatt-hours	Per cent of total	Thousands of kilowatt-hours	Per cent of total
United States	19,113,352	37.4	32,019,531	62.6	19,646,801	36.1	34,766,602	63.9	21,570,000	36.2	37,947,000	63.8
New England	1,215,591	33.2	2,449,011	66.8	1,394,860	37.2	2,353,676	62.8	1,490,000	35.8	2,668,000	64.2
Middle Atlantic	4,074,499	31.0	9,069,637	69.0	4,518,290	32.5	9,381,381	67.5	4,700,000	30.8	10,540,000	69.2
South Atlantic	2,031,162	36.6	3,520,603	63.4	2,288,369	39.4	3,506,438	60.6	1,883,000	31.0	4,200,000	69.0
East North Central	1,484,306	12.4	10,542,089	87.6	1,694,864	13.0	11,396,240	87.0	1,532,000	10.8	12,730,000	89.2
West North Central	1,043,678	29.1	2,543,995	70.9	1,200,158	33.8	2,353,660	66.2	1,320,000	35.2	2,432,000	64.8
East South Central	992,612	54.3	834,479	45.7	1,032,503	51.6	968,878	48.4	873,000	35.8	1,565,000	64.2
West South Central	8,413	0.5	1,545,480	99.5	10,430	0.6	1,779,200	99.4	23,000	1.2	1,967,000	98.8
Mountain	2,386,333	87.4	340,229	12.6	2,468,235	86.5	381,201	13.5	2,512,000	84.3	467,000	15.7
Pacific	5,876,758	83.4	1,174,008	16.6	5,039,092	65.6	2,645,928	34.4	7,237,000	84.1	1,378,000	15.9

[1] Data collected by U. S. Geological Survey.
[a] Based on operations during first 10 months.

some states the cities have regulatory powers over the local utilities, while other districts come under the jurisdiction of the state commission. The municipally operated utilities are controlled usually by the municipal authorities and do not come under the jurisdiction of the state commissions. Experience has proved regulation to be successful, but the great differences in the regulatory powers of the different state commissions, the local activities of city commissions and the growth of Federal regulation are making regulation cumbersome and complex without adding to the protection of the consumers. Another element in the situation is the growth of the number of consumer-owners of utility securities, and it may be that the consumers may ultimately secure the best type of regulation through functioning as stockholders in the utilities serving them. Also the trend toward concentrated and large systems may serve to decrease the number of separate organizations that must be regulated to protect the public and so simplify regulation or make possible Federal regulation only. In view of the existing status of the light and power industry and the rapid changes that are occurring, it seems evident that some changes in existing methods for regulating the utilities are inevitable.

Future Growth.—The question is often asked, "When is the growth of the electric light and power industry going to stop?" This industry since 1912 has more than quadrupled its output and the revenue which it has derived from the sale of that product. The potential activities are being extended every year through new industrial and domestic applications. There is at the present time an industrial heating load estimated at over 1,200,000 kw., but a potential industrial heating load estimated at 75,000,000 kw., or three times the present connected motor load. The increased use of electrical energy in various chemical processes, the electrification of railroads, the growth in the use of the electric truck, the increased use of domestic heating and motor-driven devices and the increased use of appliances in the homes—all will contribute to the growth in the central-station output and revenue expected of the future. The placing of hundreds of thousands of radio receiving sets on the central-station lines will be an actuality of the near future, and it is estimated that by 1930 the central-station industry will derive an annual revenue of several million dollars from the radio load alone.

TABLE VI.—THE INDUSTRIAL POWER LOAD OF THE UNITED STATES IN 1924[1]

Industry	Primary horsepower						Electric motors run by energy generated in private plants, horsepower	Boilers		Number of companies having private electric generating plants
	Total primary horsepower	Owned by establishments reporting				Electric motors run by purchased energy, horsepower				
		Steam engines (not turbines)	Steam turbines	Internal-combustion engines	Water turbines			Number	Horsepower	
All industries	33,143,753	13,386,996	3,340,204	1,254,140	1,803,317	13,359,096	8,888,569	60,192	16,069,113	8,157
Chemicals and allied products	2,738,605	1,060,992	410,660	78,877	168,557	1,019,519	674,556	7,390	2,168,454	664
Food and kindred products	3,723,130	1,586,547	123,719	182,386	120,912	1,709,566	513,037	9,428	2,229,858	1,627
Iron and steel and their products, not including machinery	7,243,340	3,629,067	1,047,810	613,724	21,190	1,931,549	3,029,828	9,645	3,602,405	670
Leather and its finished products	412,961	172,329	41,722	4,256	3,884	190,770	123,029	1,406	278,705	259
Lumber and allied products	3,336,333	2,336,854	186,575	48,711	42,746	721,447	507,329	11,950	2,384,769	1,045
Machinery	2,267,185	442,383	216,403	69,064	26,522	1,512,813	740,352	2,577	613,285	746
Metals and metal products other than iron and steel	1,168,693	299,376	138,178	23,173	11,814	696,152	283,544	969	301,094	218
Musical instruments and phonographs	90,229	35,539	16,997	743	79	36,871	39,078	359	62,994	56
Paper and printing	2,742,693	798,571	194,409	15,186	886,462	848,065	653,081	2,365	774,599	576
Railroad repair shops	806,435	306,195	52,873	23,684	88	423,595	271,731	1,898	472,208	275
Rubber products	605,634	135,338	121,697	8,859	6,506	333,234	180,799	497	221,687	86
Stone, clay and glass and their products	1,919,235	729,529	117,650	92,090	30,582	949,384	424,996	3,066	798,212	555
Textiles and their products	3,800,360	1,379,328	457,772	30,112	466,364	1,466,784	911,262	6,029	1,481,865	978
Tobacco manufactures	43,481	22,587	4,574	417	0	15,903	15,254	254	41,971	44
Transportation equipment, air, land and water	1,667,968	295,405	169,057	50,490	10,940	1,142,076	453,972	969	403,466	182
Miscellaneous industries	577,471	156,956	40,108	12,368	6,671	361,368	66,721	1,390	233,541	176

TABLE VI.—THE INDUSTRIAL POWER LOAD IN THE UNITED STATES IN 1924.[1]—(*Continued*)

Industry	Estimated rating of prime movers used in private generating plants, horsepower	Estimated electrification of industry, per cent	Energy consumed			Generators in private plants		
			Total energy consumed, kilowatt-hours	Purchased from central stations, kilowatt-hours	Generated in private plants, kilowatt-hours	Total rating of generators, kilovolt-amperes	Rating of alternating current generators, kilovolt-amperes	Rating of direct-current generators, kilowatts
All industries	6,416,763	59.7	31,004,483,000	19,393,722,000	11,630,761,000	5,913,462	4,411,577	1,501,885
Chemicals and allied products	630,803	60.3	4,442,612,000	3,379,952,000	1,062,665,000	584,344	397,896	186,448
Food and kindred products	534,158	60.2	3,517,092,000	2,670,520,000	846,572,000	494,514	297,635	196,879
Iron and steel and their products, not including machinery	1,975,344	54.0	6,103,792,000	2,393,789,000	3,710,003,000	1,830,094	1,497,778	332,316
Leather and its finished products	68,462	62.8	404,164,000	243,560,000	160,604,000	63,306	36,775	26,531
Lumber and allied products	317,643	31.2	1,357,710,000	777,511,000	580,199,000	293,704	243,284	50,420
Machinery	326,802	80.9	1,694,777,000	1,190,894,000	503,883,000	302,439	184,923	117,516
Metals and metal products other than iron and steel	251,173	81.1	1,506,129,000	1,095,928,000	410,201,000	232,436	117,302	115,134
Musical instruments and phonographs	29,361	73.4	57,140,000	27,940,000	29,200,000	27,173	19,306	7,867
Paper and printing	719,154	57.2	3,986,139,000	2,262,323,000	1,723,816,000	645,262	562,441	82,821
Railroad repair shops	156,056	71.8	592,390,000	360,079,000	232,311,000	144,516	99,525	44,991
Rubber products	153,360	80.3	872,074,000	558,259,000	313,815,000	142,091	124,265	17,826
Stone, clay and glass and their products	188,634	59.3	1,638,143,000	1,139,421,000	498,722,000	173,542	122,782	50,760
Textiles and their products	662,882	56.1	2,171,102,000	1,322,071,000	849,031,000	606,584	542,402	64,182
Tobacco manufactures	13,058	66.7	39,753,000	24,829,000	14,924,000	12,101	5,175	6,926
Transportation equipment, air, land and water	309,159	87.2	2,050,946,000	1,451,914,000	599,032,000	286,379	143,137	143,242
Miscellaneous industries	80,714	76.6	570,515,000	474,732,000	95,783,000	74,977	16,951	58,026

[1] *Electrical World*. Jan. 2, 1926.

It would take a seer indeed to prophesy the ultimate limits of central-station activity or even to foresee when the present rate of annual growth is going to decrease. A certain trend has been established, however, which gives a fair basis for predicting the activities of the industry as far ahead as 1930.

Using this basis, it is believed that the energy generated by the public utilities of the country will increase from 58,990,495,000 kw.-hr. in 1924 to 85,547,108,000 kw.-hr. in 1930, or a 45 per cent increase for the 6-year period. These figures include energy generated by purely electric railway companies as well as by electric light and power companies. The rate of hydro-electric growth is also fairly well established. In 1924 approximately 34 per cent of total electrical output was generated in hydro-electric plants and 66 per cent in steam plants. In 1930 it is estimated that the proportionate amount of energy generated in hydro-electric plants will have decreased to 31.5 per cent and that generated in steam plants increased to 68.5 per cent.

CHAPTER II

DEFINITIONS AND TERMS

Many definitions and terms peculiar to the light and power industry have been adopted because of their usefulness. Not all of them are clearly defined or definitely used in any one country, but there is a gradual tendency for their universal adoption because they are convenient and expressive of facts that deal intimately with the operation of the systems. As given here, the definitions conform to those printed in the Standardization Rules of the A.I.E.E.,[1] and in addition other terms are given which will be used in the following pages in accordance with generally accepted usage.

Load Curve.—A graph plotted with kilowatts as ordinates and time as abscissae. It may apply to a whole system or to any part of the system, and the time may be taken as a day, hour, month or year. The most useful graph is made by considering the whole system load during a 24-hr. period. This curve has many uses and serves as a basic element in economic and engineering analyses of system performances. It varies with different plants and different systems and with the seasons of the year. The type and size of system very materially affect the shape of the load curve, as will be noticed from the typical curves given in

[1] *A.I.E.E. and I.E.C. Standardization Rules.*—The American Institute of Electrical Engineers has adopted a set of standardization rules which are closely followed in American practice, and the symbols, terms and definitions therein are used in the following pages. In addition, the International Electrotechnical Commission proposes and adopts standards for electrical engineering and some of these definitions or terms not found in the A.I.E.E. standards will be used in this book as given in the published standards of that body. The A.I.E.E. and I.E.C. standards can be obtained in pamphlet form at a nominal fee from the A.I.E.E., 33 West 39 Street, New York, or in handbooks. In addition to the foregoing standardization bodies, the Standards Committee of the Federated American Engineering Societies is working diligently to secure uniform national and international standardization rules. Also the National Electrical Manufacturer's Association and the National Electric Light Association pass upon certain commercial standards.

Fig. 7. For a study of yearly operations, the load curve is frequently modified by using, for example, the aggregate kilowatt-

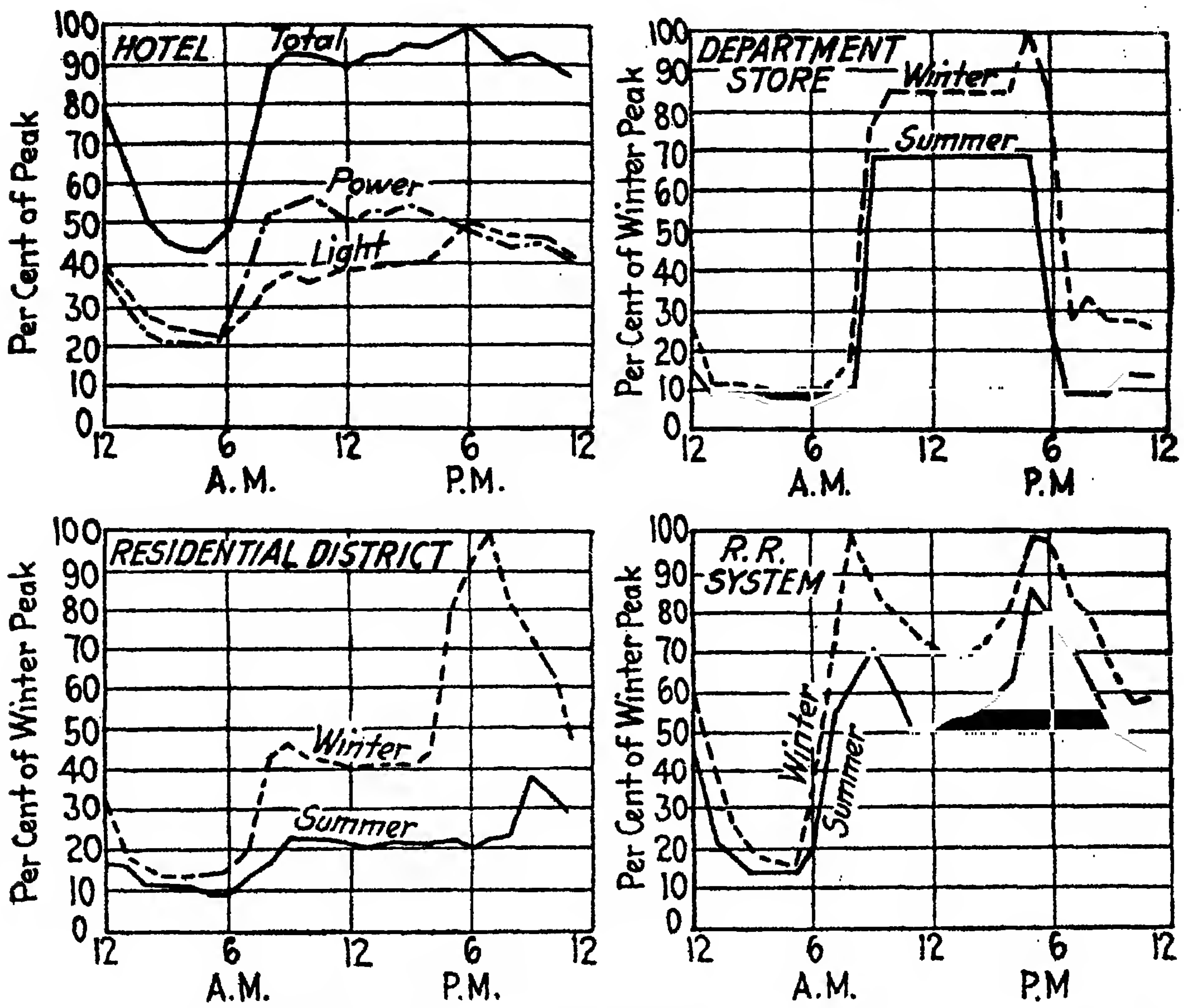

Fig. 7.—Characteristic curves of the daily loads found on a large system.

hours for 5-day periods as ordinates, as is indicated in Fig. 11. Another useful method is to make the daily load curves on card-

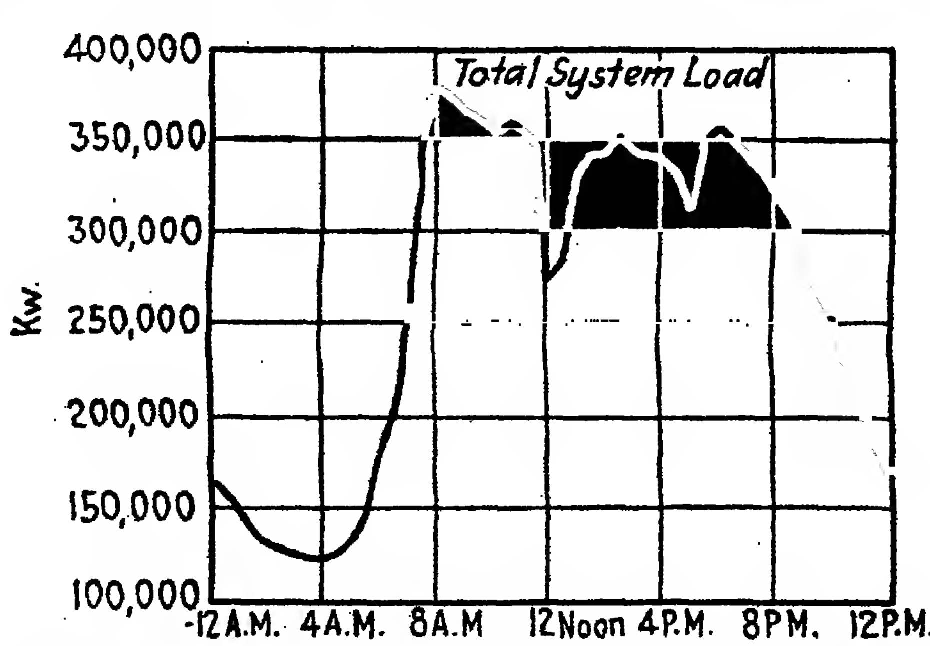

Fig. 8.— Daily load curve of a system supplying an industrial district.

board and then cut the cards to give a profile of the curve. These cards can then be inserted in a card index box each day and the

growing group of cards affords a very striking picture of the changes in magnitude and time of the system load. A very marked difference occurs in the load characteristics of different industries and the seasonal effect is also very noticeable. This is illustrated in the curves shown in Figs. 8, 9, 10 and 12. A weekly load curve for a large system is shown in Fig. 13.

Connected Load.—This term is used to denote the aggregate continuous rating connected to a system or part of a system.

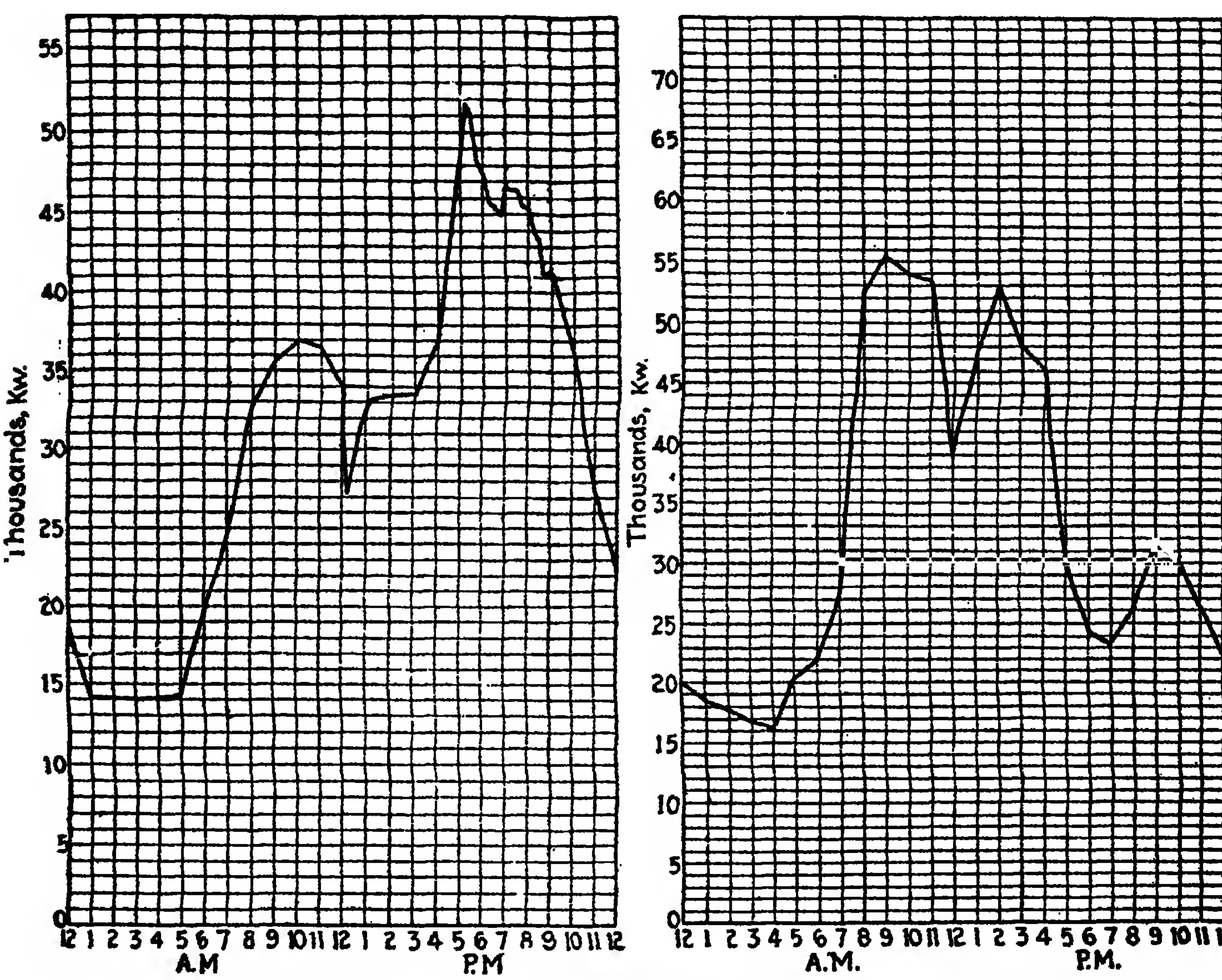

Fig. 9.—Daily load curves of companies supplying two different kinds of communities. (*a*) Lighting and commercial with a few large industrial users. (*b*) Diversified industrial load.

It may be applied to the whole system, a generating station, a substation, a transformer or other subdivision. The rating of the equipment connected is taken from the name plates of the energy-using apparatus. The load is measured in kilowatts, kilovolt-amperes or horsepower.

Rated Capacity.—The total rating of a system or part of a system that is useful and available for commercial purposes is called the "rated capacity." Capacity as such is rather indefinite and may be said to be the possible output without exceeding any of the physical limitations of the system or its equipment.

Rated capacity of a power station, for example, is that part of the sum of the name-plate ratings of the generators in kilovolt-amperes that may be available for consumers. As normally used, a station having five 30,000-kva. generators installed is said to have a rated capacity of 150,000 kva., yet this same station might carry more or less than this load, depending upon the capacity of all energy equipments and the permissible overload allowed on the units for certain time intervals.

Plant Use Factor or Plant Factor.—These terms are used to denote the ratio of the average annual load to the rated station capacity. Sometimes it is computed by dividing the gross kilowatt-hours generated by the main units in the station and

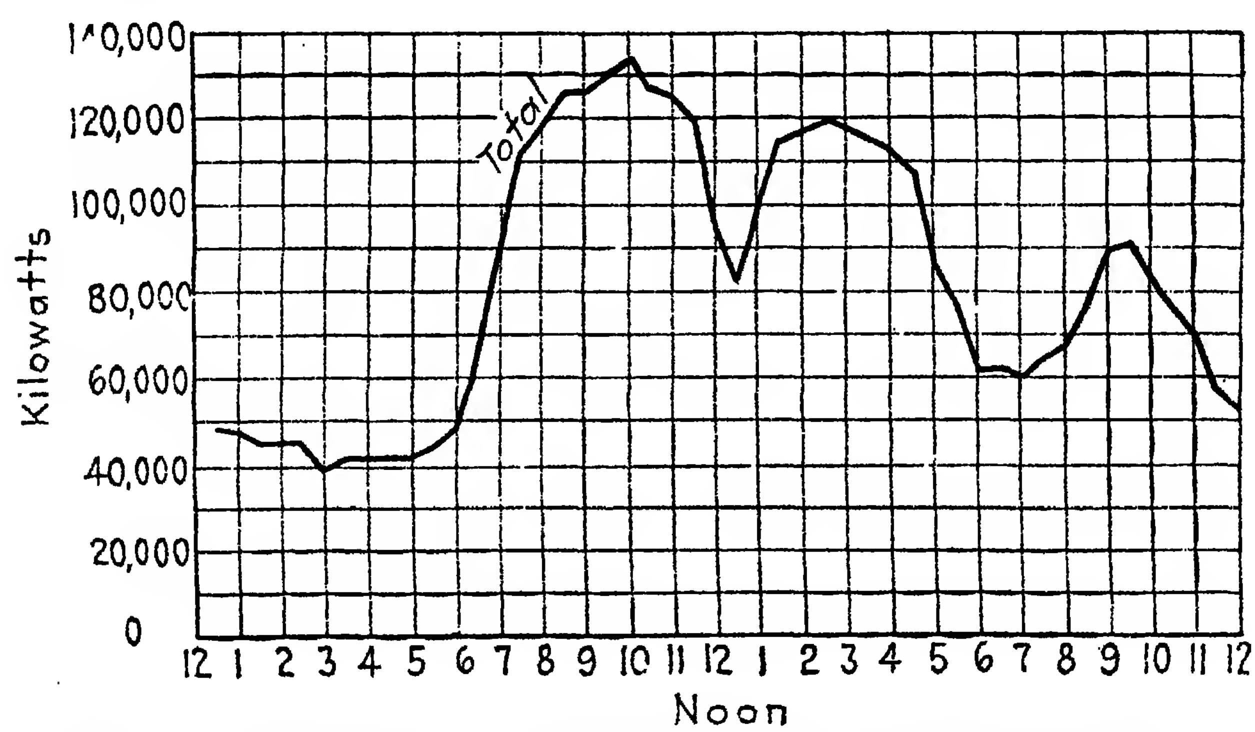

Fig. 10.—Daily load curve of a very large transmission system.

then dividing this value by the rated capacity in kilowatts multiplied by 8,760 hr. Other times it is convenient to use the average annual kilowatt or kilovolt-ampere load and divide this by the corresponding rated kilowatts or kilovolt-amperes. In some cases net kilowatt-hours are used in computing this factor; *i.e.*, the energy used for auxiliaries is subtracted from the gross energy generated.

Load Factor.—This term is computed usually by finding the ratio of the average load to the peak load in a specified time interval, such as a day, a month or a year. A definite meaning for the term can be given only when the period of peak load and the time interval considered are given. In many stations the load factor on an annual basis is found by dividing the gross kilowatt-hours generated during the year by the greatest half-hour peak

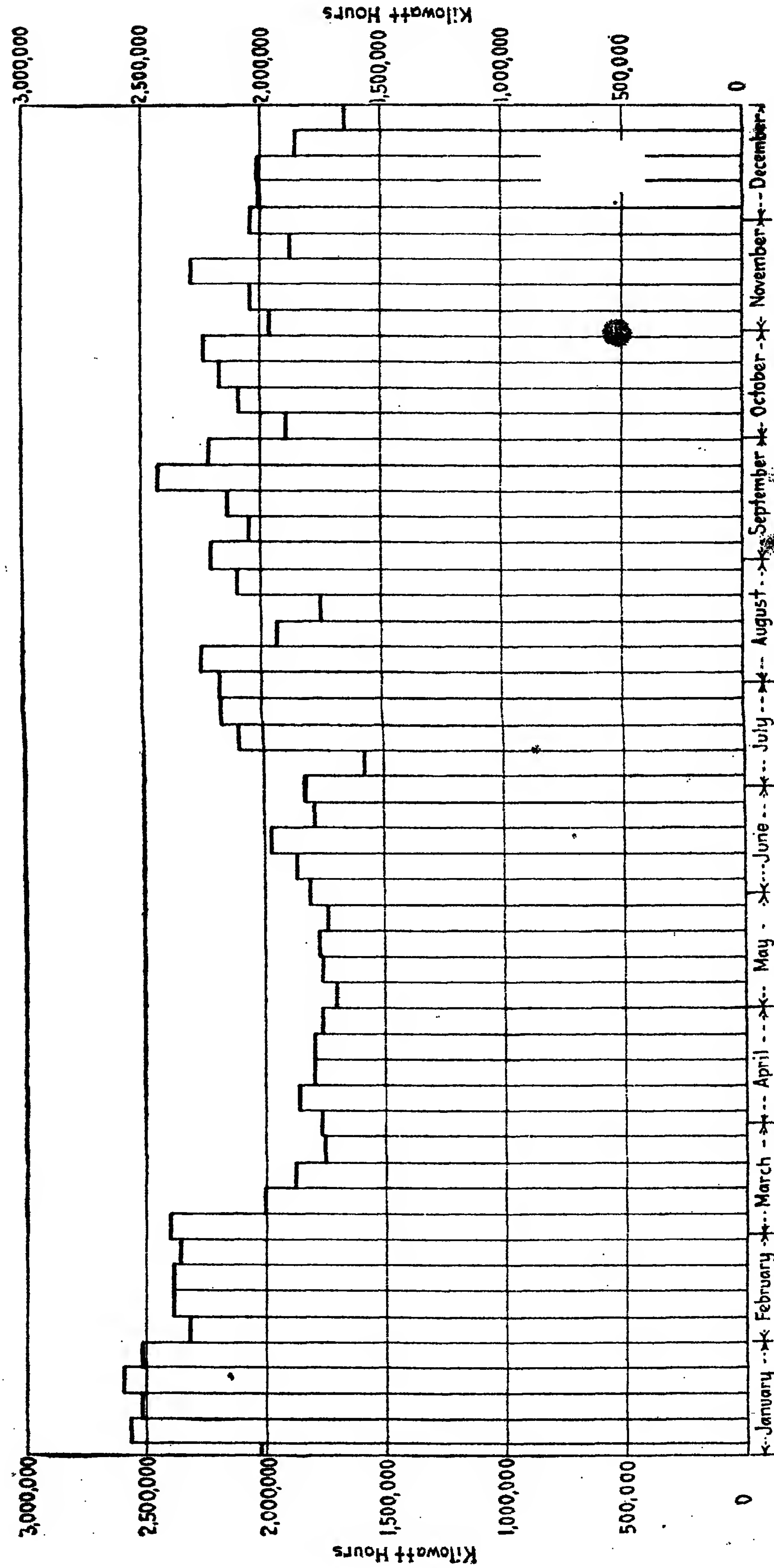

FIG. 11.—Annual load curve of a large system having steam and hydro stations and, in addition, purchasing energy.

load in kilowatts experienced during the year multiplied by 8,760 hr. In some instances net kilowatt-hours are used in this computation and in other cases the greatest hourly peak load may be used.

When graphic charts of load curves are available, a planimeter may be used to get the average load and the peak load during the period in which it is a maximum. For example, if the average load is found to be 50,000 kw. during the year and the load averages 100,000 kw. during the half hour of the year when the

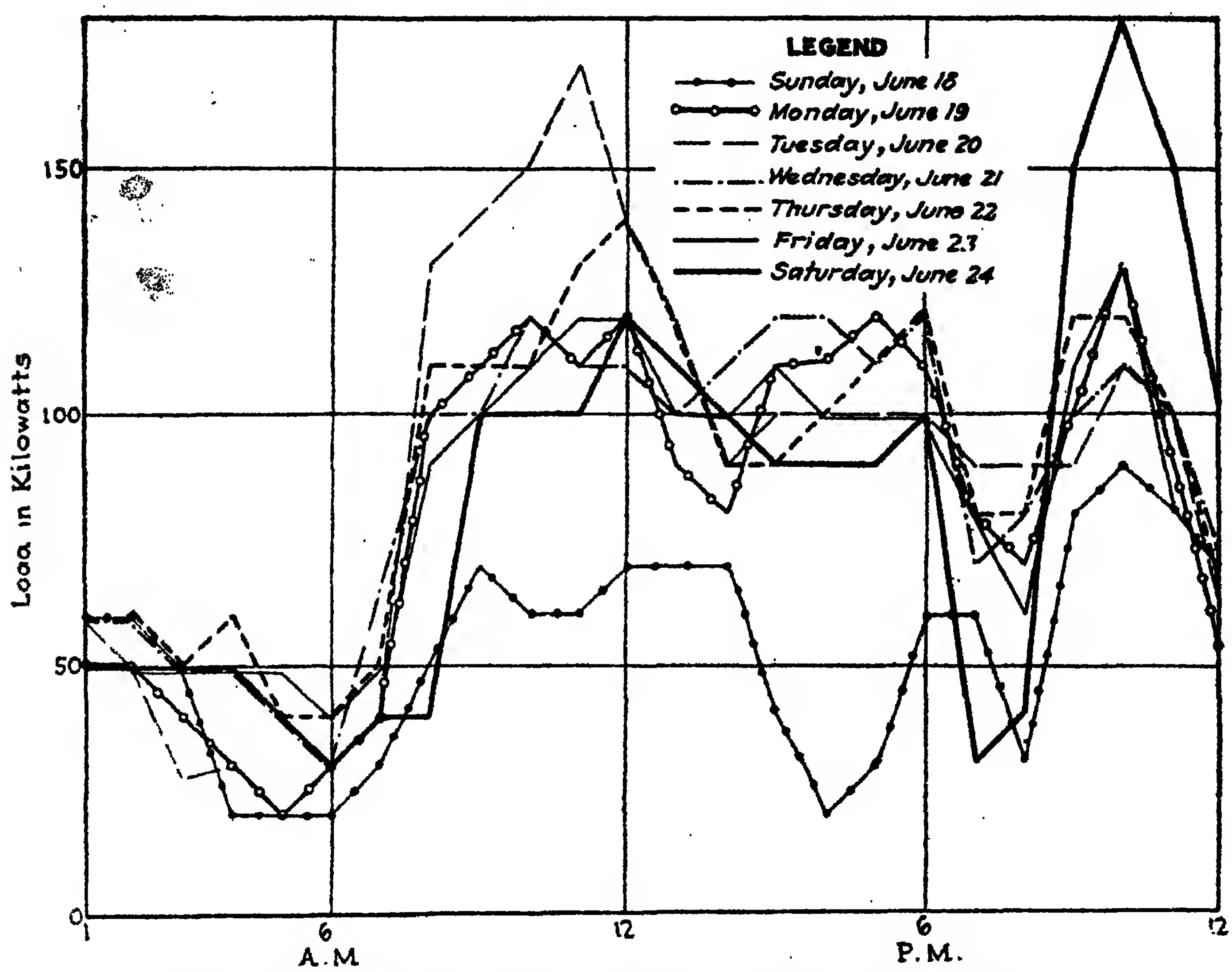

Fig. 12.—Graph showing how the daily load varies on a system supplying a community of 3,000 in an agricultural territory.

maximum load occurs, the half-hour annual load factor is 50 per cent. A high load factor is very desirable for reasons of economy. It means that the investment and the labor are used more hours for revenue-producing purposes. Most utility systems operate on an annual load factor between 30 and 60 per cent, depending on social and industrial activities and habits in the territories served. Operation at 100 per cent load factor for maximum economy presupposes no necessity for reserve equipment or time out for maintenance and repair of existing equipment. There is, therefore, a point of maximum operating economy for a system which is at less than 100 per cent load factor.

A little study will show that factories, lights, railways and other loads would have to operate continuously in order to make

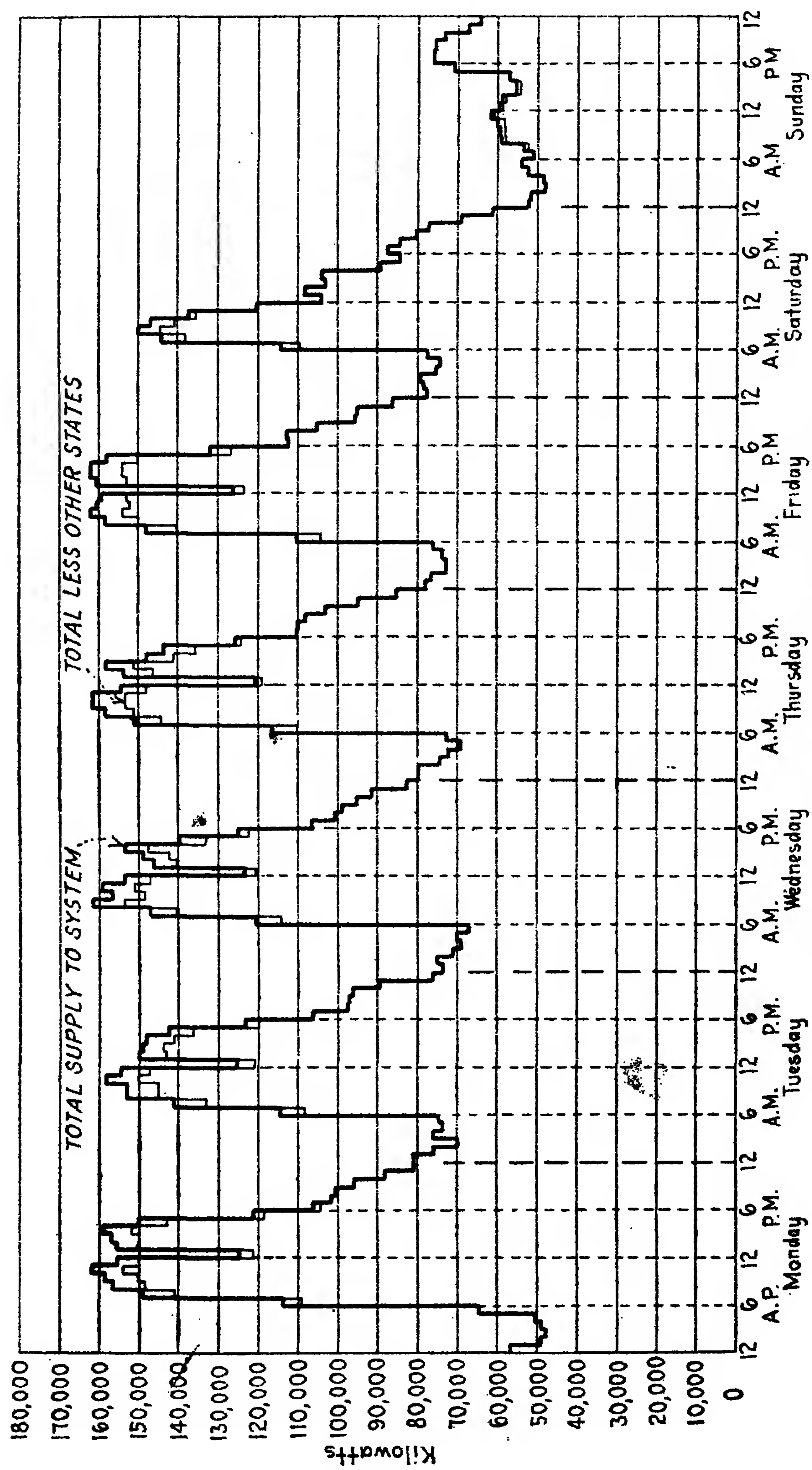

FIG. 13.—Weekly load curve for a large utility syetem.

it possible to secure 100 per cent load factor. At the same time large systems are afforded opportunities to improve their load

factor by taking advantage of time differences in industrial communities, by adding on loads of very dissimilar time characteristics and by securing a great amount of diversity in the kinds of ennergy supplied.

Sometimes load factor as referred to the consumer has a meaning that differs from the general term. In Europe, the load factor of a consumer is the same as in the definitions given, but often in this country the consumer's load factor is defined as the ratio of the average power used by the consumer to his connected load. The term "utility factor" is better for this ratio and really has the same meaning as "plant factor," although the latter term is generally applied to power stations.

Demand.—The demand of an installation or system is the average power taken from the source of supply at the receiving terminals over a certain period of time. It is expressed in kilowatts, kilovolt-amperes, amperes or other suitable units and the time interval may be an hour, day, month, year or other period as determined in the specific cases. For example, if a factory takes an average power of 100 kw. for a month's time its monthly demand is 100 kw.

Maximum Demand.—The maximum demand of an installation or system is the greatest of all the demands which have occurred during a specified period. If, for example, the factory previously considered used 150 kw. during the month continuously for, say, 15 min., its maximum demand would be 150 kw.

The power system must have an installed capacity sufficient to carry the maximum demand and not the average demand, and consequently it endeavors to reduce the maximum demands of consumers which occur at the same time as the system maximum demand. Since equipment is rated in kilovolt-amperes, the investment charge for demand can be applied best by measurements on a kilovolt-ampere basis. Any other basis introduces added elements of complexity, for example, power factor. But as a commercial enterprise it has been found difficult to determine maximum demand in kilovolt-amperes by means of known instruments or facilities, and a very common practice is to measure demand in kilowatts.

Demand Factor.—The demand factor of a system or part of a system is the ratio of the maximum demand of the system or part of the system to the connected load of the system or part of a system under consideration. For example, if the maximum

demand on a substation is 5,000 kva. and the connected load is 10,000 kva. the demand factor of the substation is 50 per cent. Demand factor is sometimes used with kilowatt instead of kilovolt-ampere measurements because of the difficulty in accurately determining the kilovolt-ampere quantities.

Diversity Factor.—The diversity factor of a system or part of a system is the ratio of the sum of the maximum demands of the subdivisions of a system, or part of a system, to the maximum demand of the whole system, or part of a system, under consideration, measured at the point of supply. Kilowatt units are usually used in determining diversity factor because they can be deter-

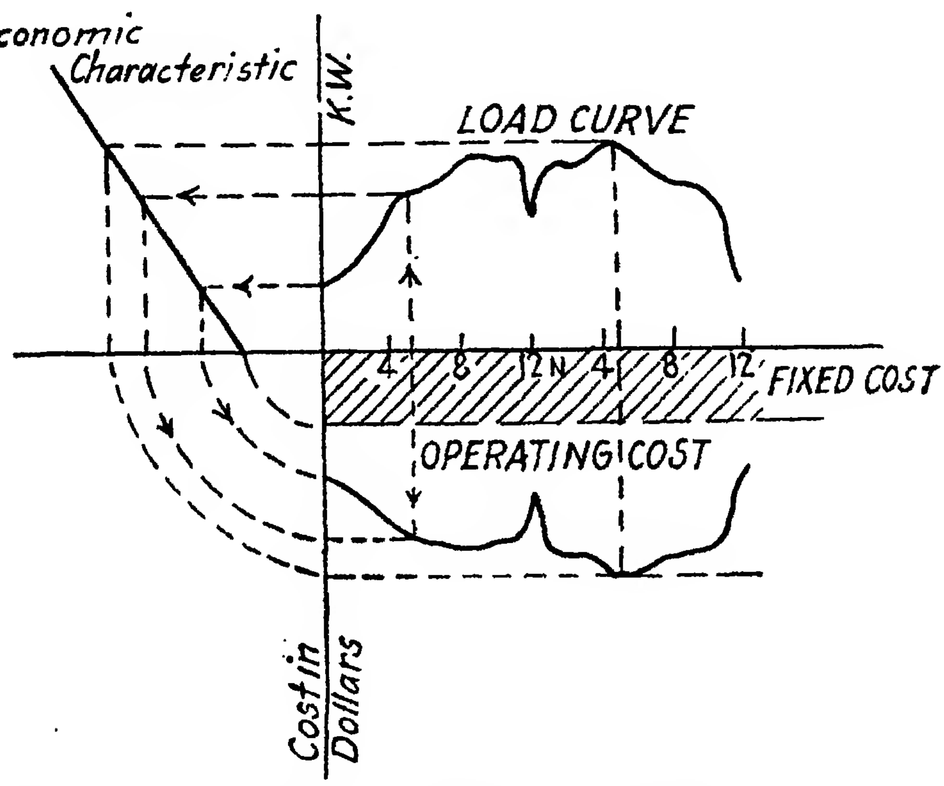

Fig. 14.—Use of the economic characteristic and daily load curve to secure the total daily costs of operation. The same principle can be applied to the annual load curve.

mined more accurately and the term is generally used in energy analyses. An example of the diversity factor of a substation may be given as follows: Assume each of three feeders has a maximum demand of 1,000 kw. but these maximum demands do not occur at the same interval of time during the day, so that the total coincident maximum demand on the substation is only 2,000 kw. Applying the ratio given in the definition, the diversity factor is 3,000 divided by 2,000, or 1.33. Diversity factor is thus a numeric and can be applied to a transformer, substation, power station or other unit part of a system. It is a very useful term in investment analyses when the ratio is measured in kilovolt-ampere units and also is convenient to use in energy analyses when the ratio is measured in kilowatt units.

Thermal or Fuel Characteristic.—A graph plotted with pounds of fuel as ordinates and kilowatt load as abscissae is very convenient for studying the operation of a power station and the term "thermal or fuel characteristic" has been given to the plot.

Economic Characteristic.—A graph plotted with the total cost of generating energy as abscissae and load in kilowatts as ordinates is called the "economic characteristic" of a station and is very useful in making cost analyses. The intercept on the horizontal axis represents the fixed cost, or that cost which is independent of energy output. This graph can be used in combination with the daily load curve, for example, to obtain a derived curve showing the area proportional to the total cost of producing energy for a daily or yearly period (see Fig. 14).

Willans Line.—A graph with total pounds of steam as ordinates and kilowatt load as abscissae is very useful in studying station thermal performance or that of any prime mover, and the name "Willans line" has been given the curve.

Tentative Definitions.—Some tentative definitions or terms often used in station practice have been made by the Prime Movers Committee of the N.E.L.A.:

Net output of a generator is the kilowatt-hours generated by the main unit in a given period modified by the following items:

1. In the case of a separately electrically driven exciter, minus the power consumed in the generator field and field rheostat.
2. In the case of a separately electrically driven ventilating fan, minus the power input to the fan.
3. In the case of a direct-connected exciter, plus the kilowatt-hours generated by the exciter minus the power consumed in the generator field and field rheostat.
4. In the case of a direct-connected auxiliary unit for supplying excitation or power for turbine auxiliaries, plus the kilowatt-hours generated by the auxiliary unit, minus the power consumed in the generator and auxiliary unit fields and field rheostats.

Boiler steaming factor is the ratio of the boiler surface hours steaming to the boiler surface hours total.

Boiler banking factor is the ratio of the boiler surface hours banking to the boiler surface hours total.

Boiler load factor is the ratio of the actual total output of a group of boilers to their actual maximum output as expressed in B.t.u. transmitted during a given period.

Stoker size is specified by the square feet of grate surface.

Heat Interchanger.—A part of a cooling system such as is used for cooling oil, air or transformers in which water or other medium is circulated in a closed loop, where heat is absorbed for the purpose of cooling in one part of the system and given up for heating in another part of the system—the latter part being called the heat interchanger.

Heat Pressure Evaporator.—A type of evaporator which operates at a pressure somewhat below boiler drum pressure where the vapors are absorbed by the feed water at upwards of 212°F.

Low-pressure Evaporator.—A type of evaporator which operates between a pressure close to atmosphere and a vacuum of 20 to 25 in. of mercury, the heat in the vapors being absorbed by the condensate.

First Effect, Second Effect.—Terms applied in the evaporation of water. When the process of evaporation takes place in two or more steps the initial step uses the heat of steam from some source external to the evaporation plant for vaporizing the water; the second effect utilizes the vapor from the first effect to vaporize the water.

Make-up.—Water supplied to boilers to make up the deficiency in supply from the condensate and the heating steam which is returned.

Total steam of a prime mover is the total pounds of steam per hour passing the throttle minus the heat extracted per hour for feed-water heating and including steam used for steam seals.

Total heat of a prime mover is the total heat of the steam per hour at initial conditions minus the heat extracted per hour for feed-water heating and including the heat per hour in the steam used for seals.

Total heat line for a turbine is a line plotted with total heat per hour as ordinate and gross turbine unit output per hour as abscissae.

Condensate.—Water consisting of steam and entrained moisture exhausted from the last stage of a prime mover and condensed and including condensed steam and entrained moisture from steam seals but not including steam or water from any other source which may pass through the condenser.

Heat Level.—A term used to designate the order of the separate successive steps in feed-water heating. The standard method of expressing the level by means of the range of feed-water pressure of the heat level is as follows:

High Heat Level.—Where the feed-water heater is working under a pressure equivalent to boiler feed or economizer feed pressure.

Nominal Heat Level.—Where the heater is working under feed-water pressures ranging from atmospheric to economizer pressures.

Low Heat Level.—Where the feed water is under vacuum.

Basic station efficiency is the calculated efficiency of a station, accounting for all those large losses which can be calculated accurately.

Economizer efficiency is the ratio of the temperature rise of the water to the difference between the inlet gas and inlet water temperature of an economizer.

Boiler Unit.—This consists of a boiler together with its fuel-burning equipment, superheater (if any), economizer or air preheater (if any), all stoker or other fuel drives, forced and induced draft fans and boiler feed pumps used solely in connection with the boiler during normal operation.

Turbine Unit.—This consists of a turbine, together with the main generators and station power generators and exciters connected to its shaft, and auxiliary apparatus used solely in connection with the turbine operation and including under these conditions condensate pump and drive, circulating water pump and drive, air-removal apparatus, oil-circulating and cooling apparatus, generator air-cooling apparatus, main condenser, heaters, exciters and their drive.

CHAPTER III

GENERAL CONSIDERATIONS FOR LOCATING STATIONS

In considering the design elements connected with the installation of an energy supply system the technical, social and economic aspects must all be considered and given proper weight. This is because a central-station property is a public utility and produces a commodity which is partly product and partly service. It has become a public necessity and is subjected to regulation by the public. And in addition it must have good public relations if it is to operate successfully. For these and other reasons the engineer must develop the project with a very broad perspective and with the knowledge that the changing state of the art prevents any predictions to be made as to the economical life of equipment or permanency in operating methods.

Economic and social conditions call for concentrated plants for producing power in large quantities and widespreading electrical systems for distributing the energy. A scrapping of obsolete and uneconomical power plants is continually going on, and mammoth new steam and hydraulic plants are being built. In studying an energy supply system it is necessary to consider all the elements along the energy stream from water or coal to the consumer, and to design with economy and reliability of service as primary considerations.

Area for Power Supply.—Without considering the effect of interconnection with other systems, the area over which energy is to be distributed has a very decided bearing on the location, type and size of the engineering equipment to be used. The size and the number of power stations, the voltage for transmission, the number and the size of substations and the total cost of energy to the consumers are all influenced by the size of the territory served. A large area is advisable from the standpoint of installed capacity because it permits the system to take advantage of the economies available through diversity differences, load density differences and local operating differences. Also it permits the development of lightly loaded territory most economically. But the reduction

in cost of energy does not continue indefinitely with an increase in area, because the cost of transmission begins to mount, the transforming equipment at the higher voltages becomes more expensive and other elements change conditions so that the reliability of the service rendered may become less as the territory exceeds a certain limit. Also it may come about that the cost of the overhead organization becomes excessive and the administration and operating systems become cumbersome and inefficient.

Estimate of Load.—It is very difficult to estimate the probable load in a given territory. If stations are in existence, the load data can be obtained, but in other localities a rough estimate may be made of average conditions in the following manner: (1) Averages show a per capita consumption of about 100 kw.-hr. per year for domestic use, of about 20 kw.-hr. for street and commercial lighting, of 15 kw.-hr. for street railways and of about 350 kw.-hr. for power. Allowing about 20 per cent for losses and knowing the number of inhabitants, the total kilowatt-hour consumption per year can be estimated. (2) Knowing the aggregate kilowatt-hour output per year, the rated generating capacity necessary to install can be found from the fact that average conditions call for 1 kw. of station capacity for each 2,300-kw.-hr. annual output. This method is very approximate and, fortunately, it is seldom necessary to use it in this country because of the existing developments. The fact that interconnection between territories is the present trend also very materially modifies the assumptions, since energy may be sold or purchased from neighboring systems as necessity or economy dictates.

Location of Power Stations.—In a large area for power supply it generally proves economical and good practice to use a system of interconnected power plants rather than one large plant. This practice takes advantage of diversity, permits shorter lines to be used, makes possible stations near the center of load in the heavily loaded districts and permits stations to be located to take advantage of fuels, water power sites or plant sites most suitable for economical operation. If the density of load is uniform in a given area it makes little difference in overall economy if multiple stations are used instead of a single station—even the copper economy will be about the same. In a large territory, unit subdivisions may be made, each of which will be served primarily from its own power station. The location of these unit stations at the weighted load centers can be found in several ways. The

theoretical solution has been determined by Dr. A. Russell[1] and simple kinematic solutions have been developed by others.[2] But as a practical proposition, theoretical solutions on a center of gravity or equality of copper loss basis are of little use in locating stations and simply serve as checks and steps in the analyses. Load centers change with lapse of time and in a given area other elements fix the station location. Hydraulic stations are fixed by the location of the water power resources and, strange to say, water also is the primary item that locates a steam station. In summer weather from 400 to 1,000 lb. of cooling water will be required per pound of fuel used in order to supply circulating

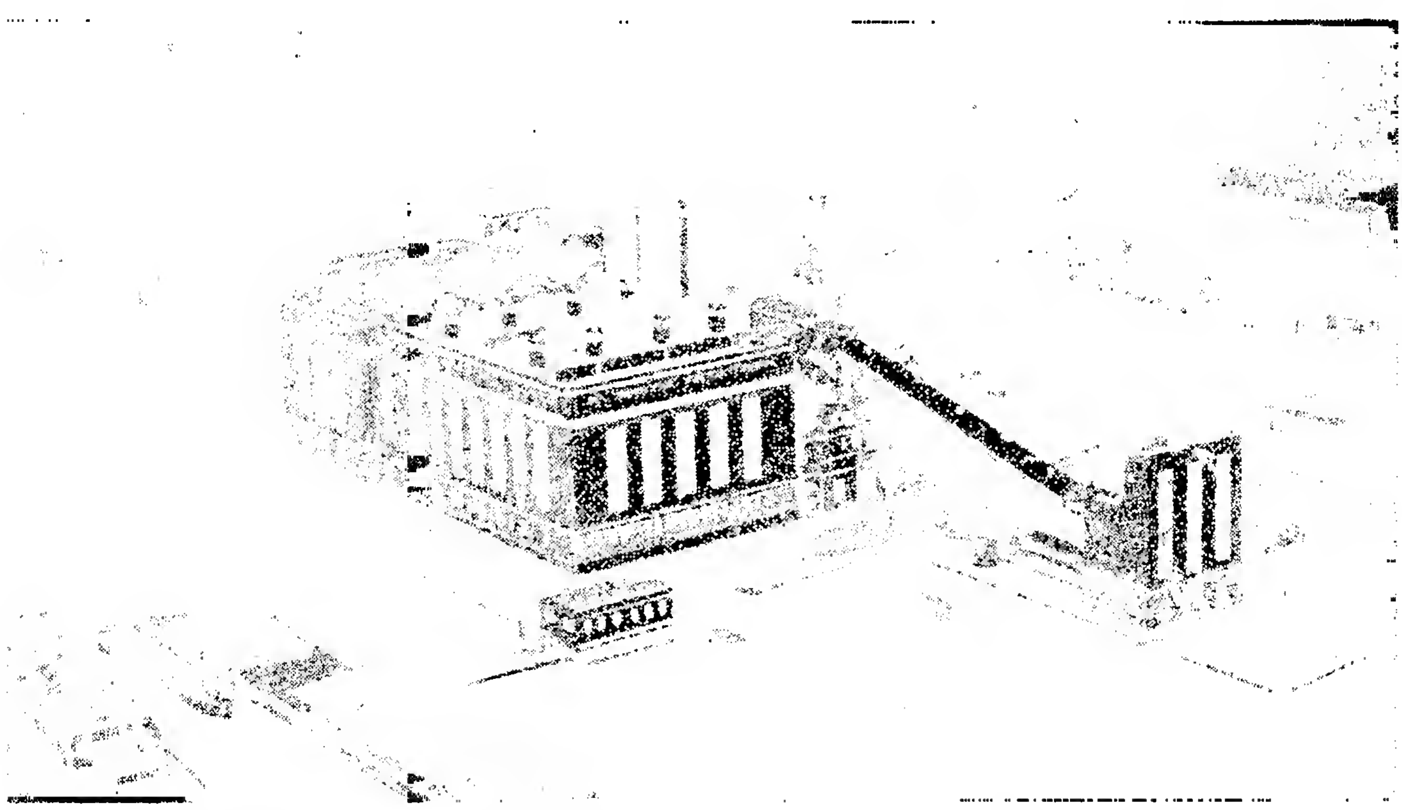

FIG. 15.—The 200,000-kw. Delaware station of the Philadelphia Electric Company presents attractive architectural features.

water to the condensers. This is a very large volume of water for large stations and it is difficult to find sites with such a water supply available. Mouth-of-mine plants, in particular, may have plenty of fuel at their doors and no circulating water—and the latter cannot be transported very readily. Next to water supply, fuel must be considered, and rail, water and highway delivery routes are necessary to safeguard the supply of fuel. Then many other things must be considered, such as the availability for installing transmission lines or underground cables, the cost and amount of the land required, the soil conditions for foundations, the availability of laborers and the surrounding

[1] British Institution of Electrical Engineers, January, 1921.

[2] CARROTHERS, C. G., British Institute of Electrical Engineers, January. 1921.

architectural and social standards. In addition, smoke and building ordinances, the developments to be expected in the future and other elements must be considered. Fortunately, in a given territory, a brief analysis soon reduces the possible sites to a small number and laborious analyses are not necessary. If, however, the area is very extensive, such as would be considered in a national or regional power scheme, it would be necessary and profitable to make several fundamental analyses before locating the stations.

Effect of Load.—In any area the load varies in density throughout the territory, and consumers are conveniently divided into three classes as follows:

	Kilovolt-amperes
Domestic consumers	0–10
General power consumers	10–5,000
Large power consumers	Over 5,000

This classification is not standardized and the loads given are simply illustrative of typical divisions. In general, the area and the types of loads in the different districts materially affect the voltages used on the system. It is best to use a minimum number of voltages for transmission and distribution on a given system, as it simplifies the operation and reduces the investment in reserve equipment. The general classifications of voltages are not standardized, but the following table is typical of those for which equipment is available:

Generation	2,300, 6,600, 11,000 13,200 and 18,000
Transmission	13,200, 22,000, 33,000, 44,000, 66,000, 110,000, 132,000 and 220,000
Primary distribution	6,600, 11,000, 13,200 and 22,000
Secondary distribution	2,300, 4,000, 6,600, 11,000 and 13,200
Domestic distribution	110 and 220

Economic analyses usually fix the voltage to use in transmission, and the amount of energy and the distance are the deciding elements. Distribution limitations, safety, legal restrictions and other elements affect the choice very greatly as the consumer is approached with the supply lines. The demands, size of individual loads and their locations, number of consumers and the type of loads and their locations are to be considered in the study of the system to be used for secondary power distribution.

Analyses of Costs.—First cost and yearly total operating cost are the two major elements to be determined in the financial analyses to be made. The most intangible cost to estimate is that for depreciation and obsolescence. The life of the physical apparatus is limited and its first cost should be regained during its use in order to retain the initial capital investment but it is difficult to determine the life and to allot an equitable rate for yearly depreciation. Obsolescence, however, is usually more indeterminate than depreciation because no one can predict the economic life of equipment, for the advances in the art, particularly in the power field, are so rapid that innumerable instances are found in which equipment has been replaced because more economical apparatus has been made available.

Many of the large organizations having each year a gross income of great magnitude do not attempt to establish funds to care for this part of the yearly overhead cost but prefer to maintain a reserve fund of a certain magnitude and to maintain their investment in *status quo* by charging all capital replacements as operating costs. Small properties cannot afford to do this, as the loss of the power station, for example, would represent too great a proportion of their investment and their operating income is insufficient to permit of capital replacements of any magnitude.

The costs, first and total yearly operating, must be determined for the whole system, which includes:

Power stations, transmission system, distribution system and substations, including all organization and administration costs. And in dealing with costs in one portion of the system sight must not be lost of the effect on the costs of the other portions.

The fixed charges on a system usually include the cost of carrying the investment and provide for the replacement of worn-out or obsolete apparatus. Interest and taxes are direct charges on the investment, while insurance and depreciation cover the replacement element. Interest charges are variable, depending on conditions and the credit of the borrower. From 5 to 8 per cent are usual figures with 7 per cent a safe value to use in estimates on sound projects. Taxes vary also and range from 0.5 per cent on some hydro-electric installations to 3 per cent for some steam station installations. An average figure for estimates is 2.5 per cent when the exact value cannot be determined. Insurance against fire is obtained usually at a cost of 0.5 per cent, but many added clauses and types of insurance may increase this cost con-

siderably. Depreciation cost varies with the different equipments used on the system and their value as scrap at the end of their life. The depreciation charge may include functional and physical depreciation and is computed in many ways Different courts and state commissions have approved typical depreciation rates of the straight-line character as follows:

	Per Cent
Transmission lines	5
Boilers	5
Buildings	2
Cables	5
Coal and ash-handling equipment	7.5
Turbo-generators	7.5

But these are given as typical semi-legal figures only and vary in the different states. In setting up the accounting system for an energy supply system, depreciation should be considered for each of the accounts carried on the books and should be based on a detailed study of local conditions of operation, climate and use.

Load factor has a decided bearing on costs, as the fixed charges vary inversely with this factor, and since the no-load costs are very largely determined by the size of station or peak load, it is important to consider the monthly load factor in studying labor costs. The operating charges for a plant, especially labor costs, are influenced by load factor, since the shifts must be manned in sufficient strength to carry the peak loads. Coal costs are also influenced by load factor, for the number of units used and the rating at which they work vary with load conditions.

General Design Features.—The general design of a system is best made by treating the stream of energy from the source, through the conversions and transformations to the point of utilization. It then becomes possible to study the available equipment for treating the energy at each point and to analyze the costs and losses involved with different assemblages of equipment and different methods of operation. Aside from these major elements, others must be considered, such as reliability of equipment or service, convenience in operation and relations to other phases of the business. In general, the solution is made by balancing costs against losses for each assemblage of equipment after a study has been made of present and future conditions. More and more it is becoming necessary to study the economics of the layout and to secure the highest possible efficiency. It must

be remembered that losses are also involved in operating a system through a human organization and that these intangible losses may be large or small depending upon the efficiency of the administration and the convenience of the system for most economical operation.

When interconnected systems are considered, analyses must be made for the specific conditions and care must be exercised to consider all the elements that enter into operation and installation.

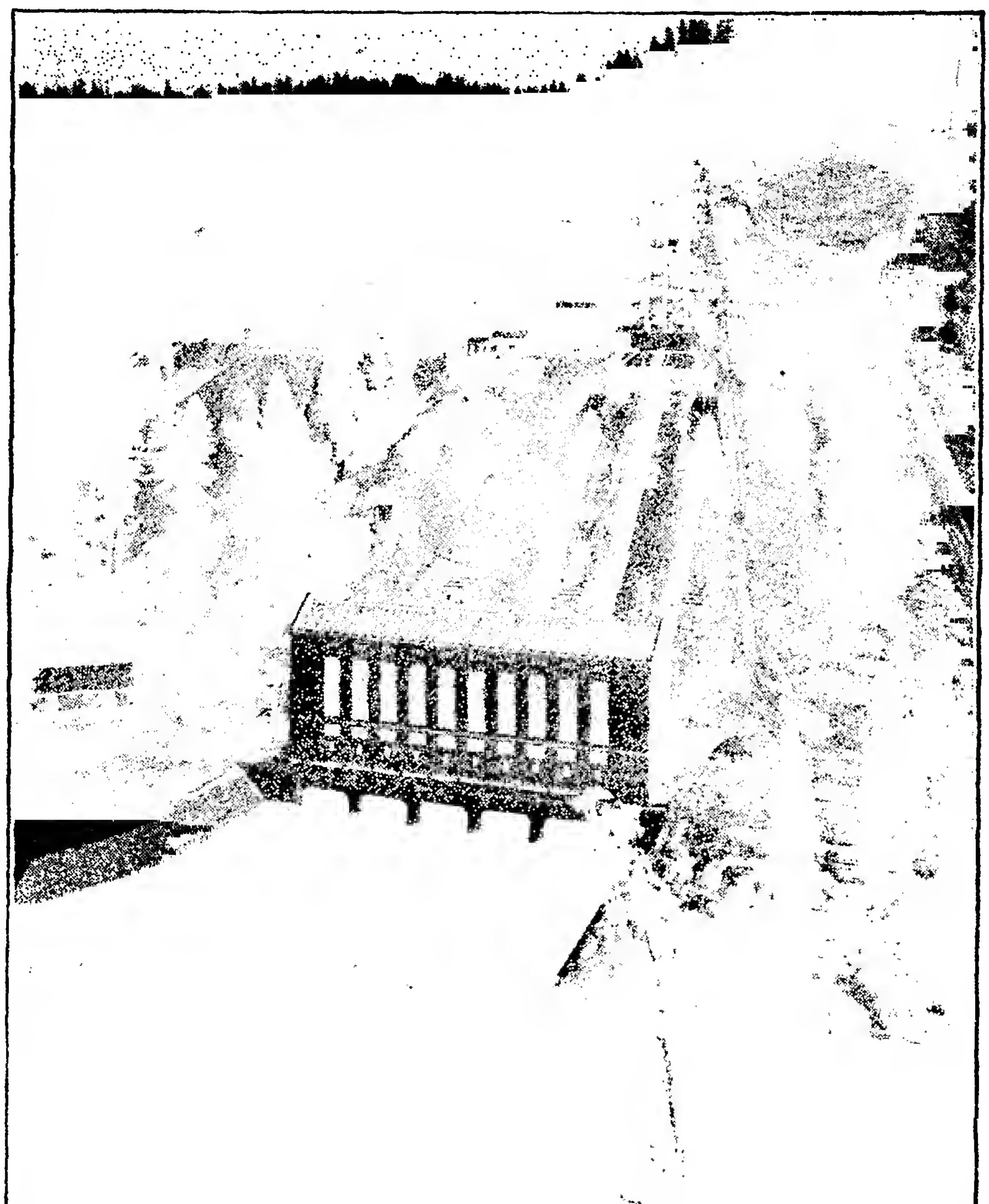

FIG. 16.—The 81,000-kva. Pit No. 3 station of the Pacific Gas and Electric Company is illustrative of well-designed hydro stations.

Plant Sites.—A central-station plant is a complex grouping of men, material and equipment for the conversion of energy with safety, efficiency, economy and convenience. Major elements to consider in laying out the site are the cost of the ground area required for immediate and future use, the accessibility of the

site for water, rail and electrical transportation, the location of the site with respect to the load and the availability for getting the energy from the station, the soil conditions for foundations, the facilities for building the plant both as regards labor and materials, storage facilities for fuel, water or ash, and other surrounding conditions that may affect operations.

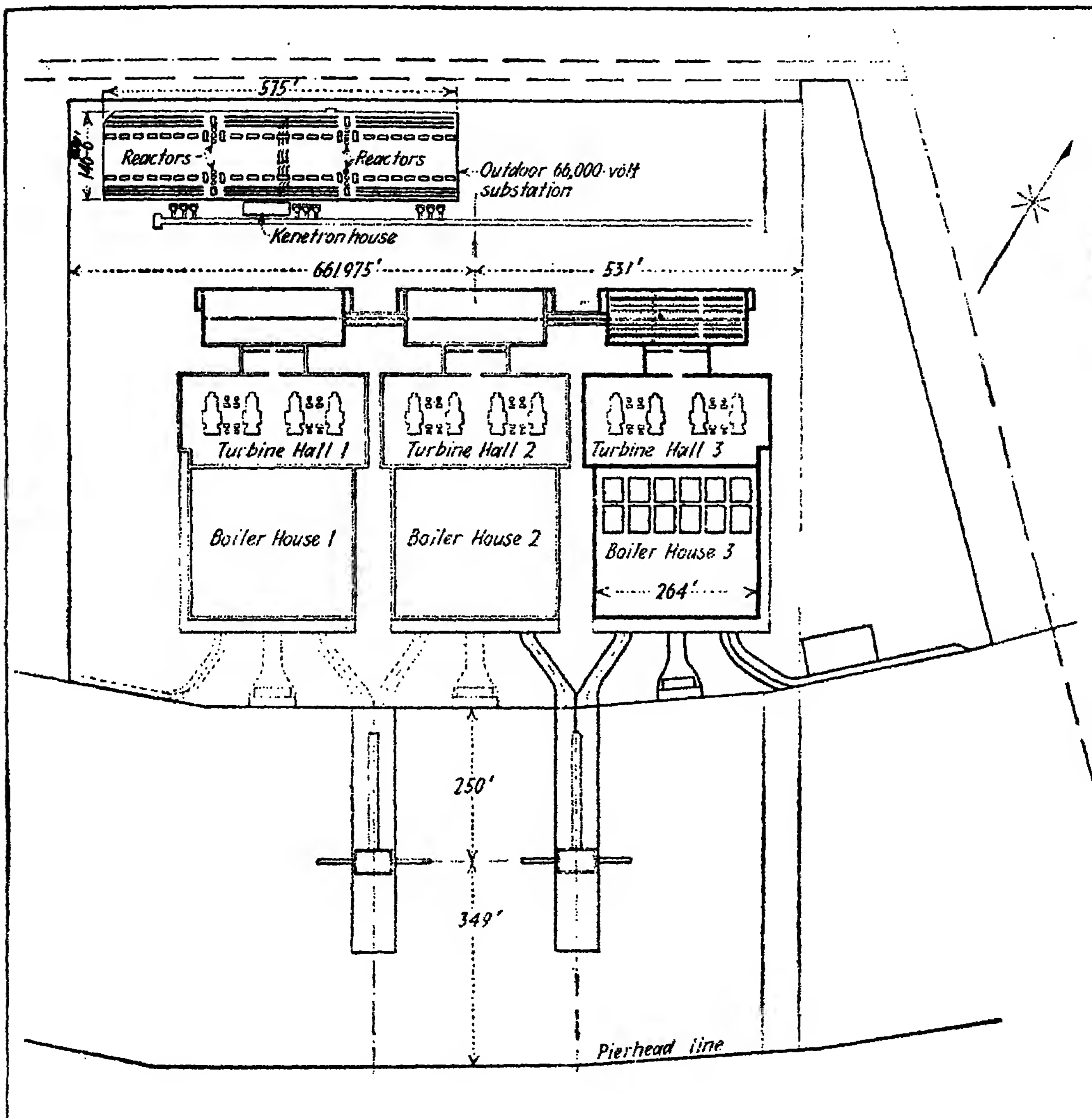

FIG. 17.—Layout of plant site for the 600,000-kw. Richmond station of the Philadelphia Electric Company.

The layout of the site and the architectural features of the buildings should be such as to add to the beauty of the surroundings without involving unnecessary expense because this practice aids public relations. European practice in this respect is superior to American but the newer American plants are better designed and often become the objects of community pride.

The terrain has a great influence on the layout for both hydraulic and steam stations. In the hydraulic plants the maximum head of water should be utilized and in steam stations the level of the condenser circulating water and transportation facilities for fuel and ash are very influential elements.

The number of buildings required depends on the size of plant, the type of plant and the voltages used. Much leeway is afforded

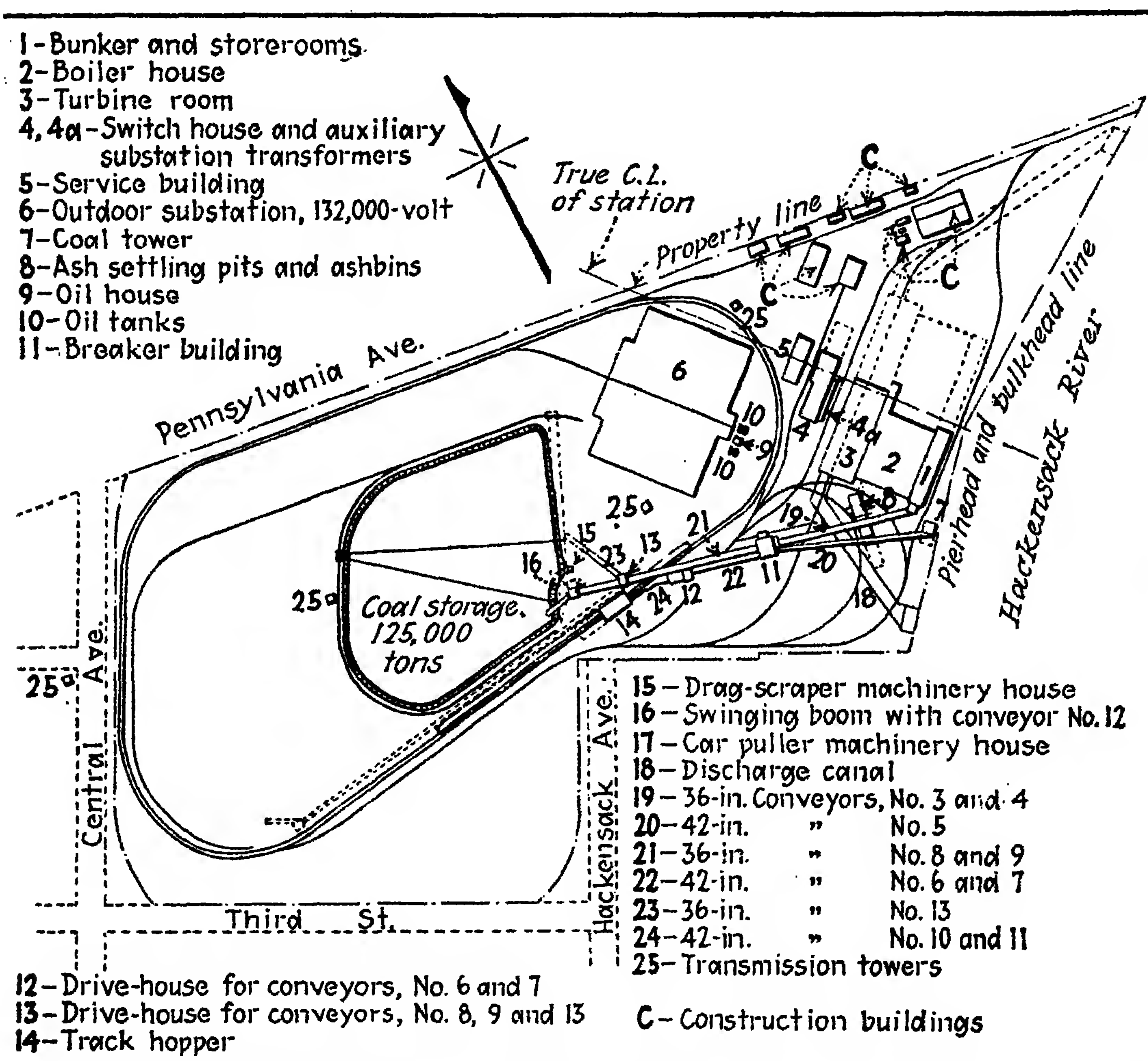

FIG. 17a.—Property-site layout for the 400,000-kw. Kearny station of the Public Service Electric Power Company.

designers as regards the amount of equipment to be housed in buildings, and the present tendency is toward a greater use of outdoor installations on account of the high cost of construction, greater operating safety and convenience. The high-tension and electrical apparatus, including arresters, transformers and switches, are usually placed outdoors and the fuel-handling and preparing equipment of the coal storage yard is also conveniently located outdoors. An economic and operating study

is required to determine the practice to be used in a specific station.

The governing element in the layout of the site is to secure the most direct route for the energy through the production process but reliability at each location may modify this condition to some extent, as may also reserve or alternative methods of operation in case of emergencies. Storerooms for supplies, homes for attendants, offices for the operating force, a hospital, locker rooms, repair shops, a restaurant, a laboratory and an assembly room are some of the other necessities that must be provided, depending on local conditions. Some of these can be incorporated in separate buildings to good advantage and others can be located in the power plant building.

Great attention should be given to the layout of the buildings and their interiors to protect the men and equipment from dirt, floods, accidents, fire hazards and other conditions beyond the control of the operating force.

Foundations.—Soil conditions for foundations should be determined by a thorough test, using closely spaced dry borings. The foundations should be uniform in depth and homogeneous in structure. Table VII gives representative data on the bearing power of soils, as given by Ira O. Baker:

Table VII.—Bearing Power of Soils

Kind of Soil	Safe Bearing Power in Tons per Square Foot
Rock—hard, in thick layers	200
Rock—equal to asphalt masonry	25 –30
Rock—equal to best brick masonry	15 –20
Rock—equal to poor brick masonry	4 – 6
Clay—dry, in thick beds	2 – 4
Clay—soft	1 – 2
Gravel and coarse sand, well cemented	8 –10
Sand—compact and well cemented	4 – 6
Sand—clean dry	2 – 4
Quick sand, alluvial soils, etc	0.5– 1

A mat foundation at one elevation on gravel earth, for example, forms a desirable type of foundation. It should be equally strong throughout so that equipment may be arranged as desired and subfoundations can then be built up from the mat to hold the units used. The unit piers are kept separate from each other

and from the floors to prevent vibrations and expansions being communicated over a large area. Reinforced-concrete foundation construction is, in general, better than mass concrete construction, as it takes less space, but care must be taken to protect the reinforcing from exposure to electrolytic action. For the prime mover units, mass concrete, reinforced concrete and steel are used, and where space is very valuable an all-steel foundation may be used.

When foundations are built on solid rock, the top surface should be cleaned and have a dressing of concrete to bring it to a level. When the foundation is to be clay or dry sand, the foundation does not need to be carried deeper than the frost line, as a mat-type foundation must be installed. When wet soils or loose alluvial soils are encountered, it is necessary to use piles, and the safe bearing power of the piles may be obtained by use of the *Engineering News* formula for piles driven by a drop hammer:

$$P = \frac{2wh}{S+1} \text{ tons safe load.}$$

W = weight of hammer, in tons.
h = distance of free fall of hammer, in feet.
S = penetration of pile for last blow, in inches.

The piles are driven on 3-ft. centers with a concrete mat on the top portion through which anchor rods project.

Building Construction.—The foundations and walls of reinforced concrete should be continued to some distance above ground level or above flood water and the walls then continued to the roof with a type of construction that may be brick filled structural steel, reinforced concrete and steel, hollow tile and steel, stone or a combination of these materials. Reinforced-concrete floors with steel gratings are usually used, and in the operating rooms, turbine rooms and switch galleries a special and sometimes colored cement dressing is used on top of the concrete. Tile is also used in turbine halls, but is more expensive than the surface dressing.

The interior walls should be light in color and surfaced so they may be easily cleaned. Glazed brick, tile and patent surfaces are used frequently. Doors and windows should be conveniently located and where large doors are used small doors may be cut in them for the greater convenience of the employees. The windows should be made with small panes and steel sash and should be readily opened and closed by the operators. The roof gener-

ally consists of a structural steel framework covered with patent roofing, tile, slate or tar and gravel. Care must be used to insure no water leakage and to get good ventilation and daylight illumination through the use of skylights.

The height of the building is determined by installation clearances, size and type of equipment used, the cost of land and local operating conditions. Cranes should be able to lift and move any piece of equipment without interference with the operation of other apparatus; often railroad cars enter the boiler room, turbine room or basement and the use of island construction also may influence the height.

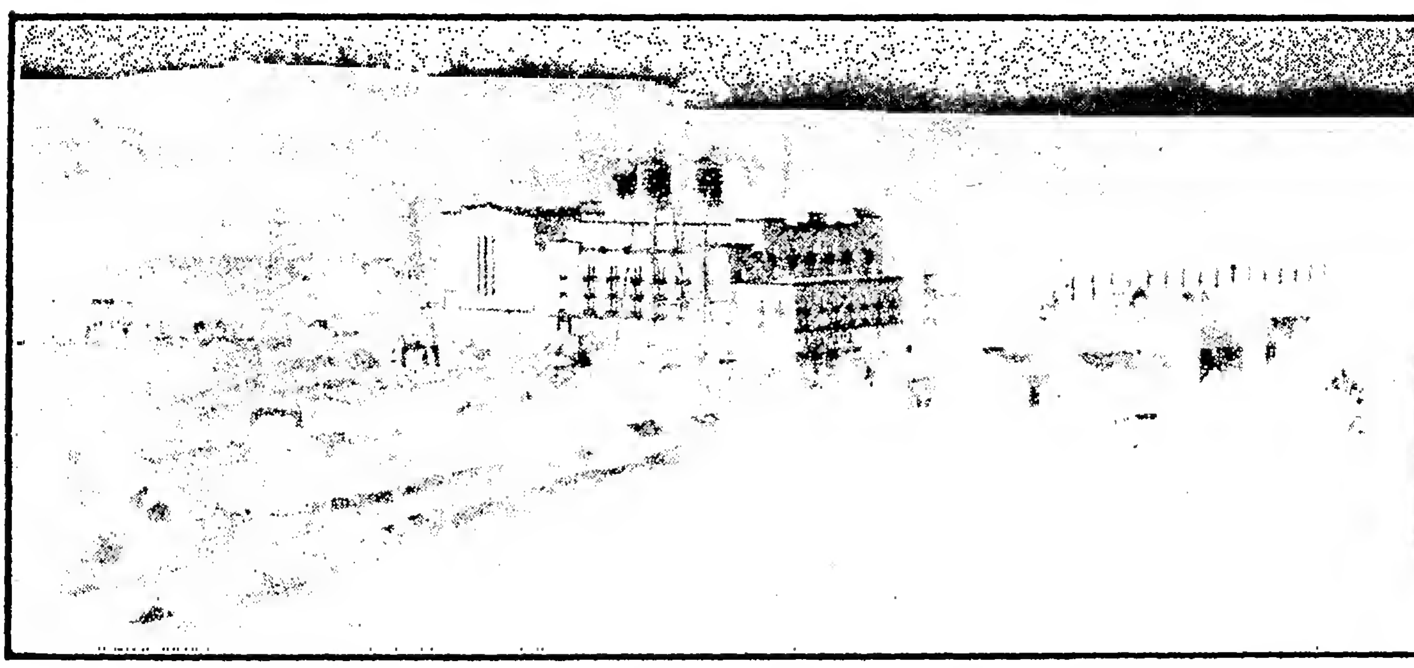

FIG. 18.—The 80,000-kva. Philo station of the American Gas and Electric Company is a base-load highly efficient plant.

Heating and Ventilating.—The heating and ventilating of the buildings is a major consideration. In the steam stations one arrangement is to take air from the outside, with or without washing, and conduct it through the rooms and into the boiler furnaces for combustion purposes. The incoming air may be heated or tempered in many ways and in winter the air from the heated machinery may be used to advantage. Warm circulating water from the condensers may also be used in an air washer to heat the air. Direct radiation using exhaust steam from auxilliaries, steam bled from main units or electric heaters is frequently used and a method for utilizing the heat in flue gases for station heating can be used. Air changes at frequent intervals are necessary to prevent condensation, and it is generally better to clean the air used in order to reduce the dirt and decrease the maintenance costs. Floor drainage, safety precautions in the

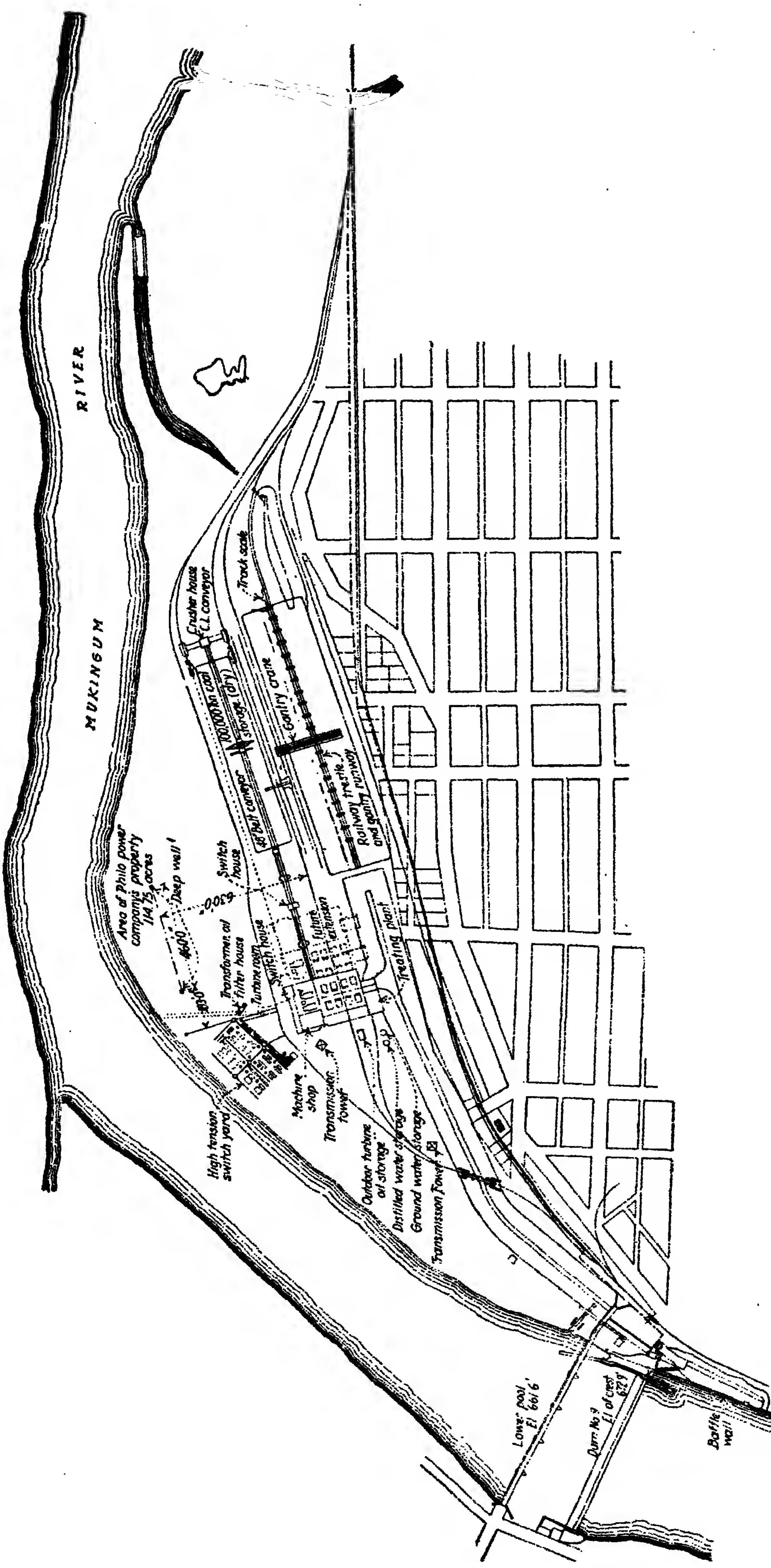

FIG. 19.—Layout of plant site for the 80,000-kw. Philo station of the American Gas and Electric Company.

way of alarms and unobstructed passages must also be secured in the design.

Boiler Room.—The boiler room requires a great volume of air for its furnace operation, as about 13 lb. are required per pound of coal burned. The air for combustion should be supplied from those parts of the station where heated air is available, if this can be done conveniently and economically. In stoker-fired boilers this air must be led to the space under the boilers and the heated air, collected from the upper levels of the station or from air heaters, must be conducted downward through spaces in which no rising convection air currents are encountered. Some of the air can be obtained from the turbine room but a great amount

TABLE VIII.—ESTIMATED COST OF 30,000-KW. OIL-BURNING SOMERSET STATION OF THE MONTAUP ELECTRIC COMPANY—1925

Yard	$ 198,700
Building	1,266,065
Equipment foundations	60,175
Boiler plant	273,400
Draft system	153,500
Feed-water system	201,500
Condenser system	379,575
Piping and covering	260,000
Fuel-oil system	50,650
Generators	525,000
Transformers	32,280
Switchgear and wiring	398,230
Auxiliary equipment	98,400
Machine shop	10,000
Tests and preliminary operation	15,000
Oil storage and handling plant in yard	120,950
Transformer repair shop	28,950
Equipment foundations and steel structure	80,600
Electrical equipment	142,500
Switchgear and wiring	157,755
Engineering cost	220,000
Construction engineering	375,840
Office at works	80,000
Inspection and expediting	20,000
Insurance	35,000
Temporary construction	160,000
Depreciation on construction equipment	50,000
Contingencies	350,930
Total	$5,745,000

(No allowance for fresh water supply from outside source is included.)

must be obtained from outside the building. If care is exercised in laying out ducts, stairways and halls, the air can be obtained without the use of forced circulation and without introducing cold drafts. It also can be admitted in such a way as to sweep away noxious gases and fumes. In cold weather, condensation will give trouble if the moist air comes into contact with heated surfaces and it may be necessary to use fans to direct air flow in certain channels.

Turbine Room.—In the turbine room, summer and winter conditions are difficult to meet and the location of the individual machines and their local temperature effects make it difficult to

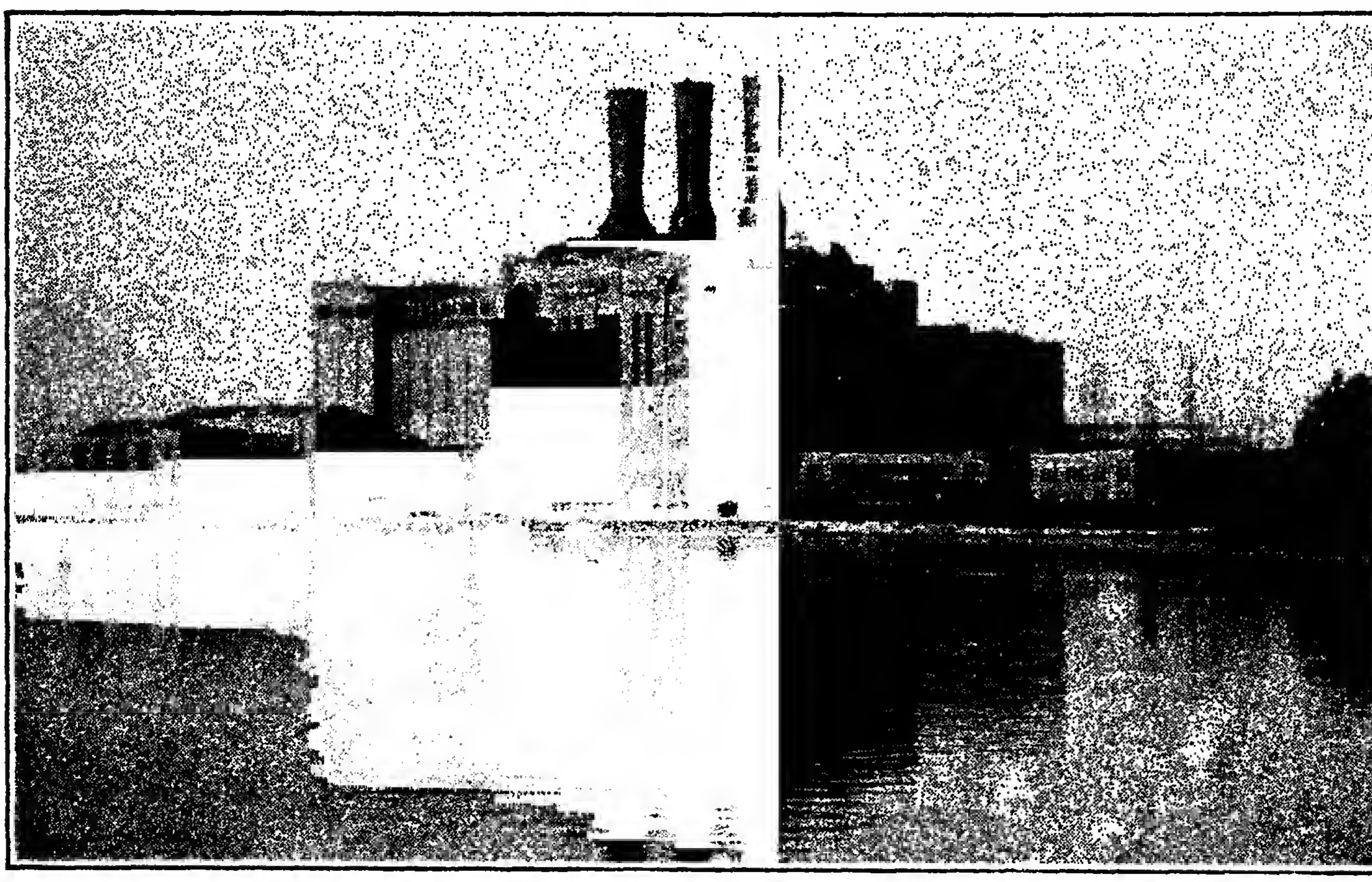

FIG. 20.—The 187,500-kva. Trenton Channel station of the Detroit Edison Company has an attractive setting.

secure uniform conditions. The windows, skylights and water pipes may cause condensation and leaks from steam lines or machines may introduce troublesome moisture. Also the use of enclosed generator cooling affects the situation materially, but if the open system of cooling is used it may be possible to exhaust the heated air into the room in winter or into the combustion chamber in summer. Thus many elements in specific installations make it difficult to specify any general solution. Forced ventilation of some sort is generally used and often exhaust steam, electric or coal-fired heaters are necessary for winter conditions.

Switch House and Bus Compartments.—Forced ventilation is best in these locations in order to sweep out any dangerous gases

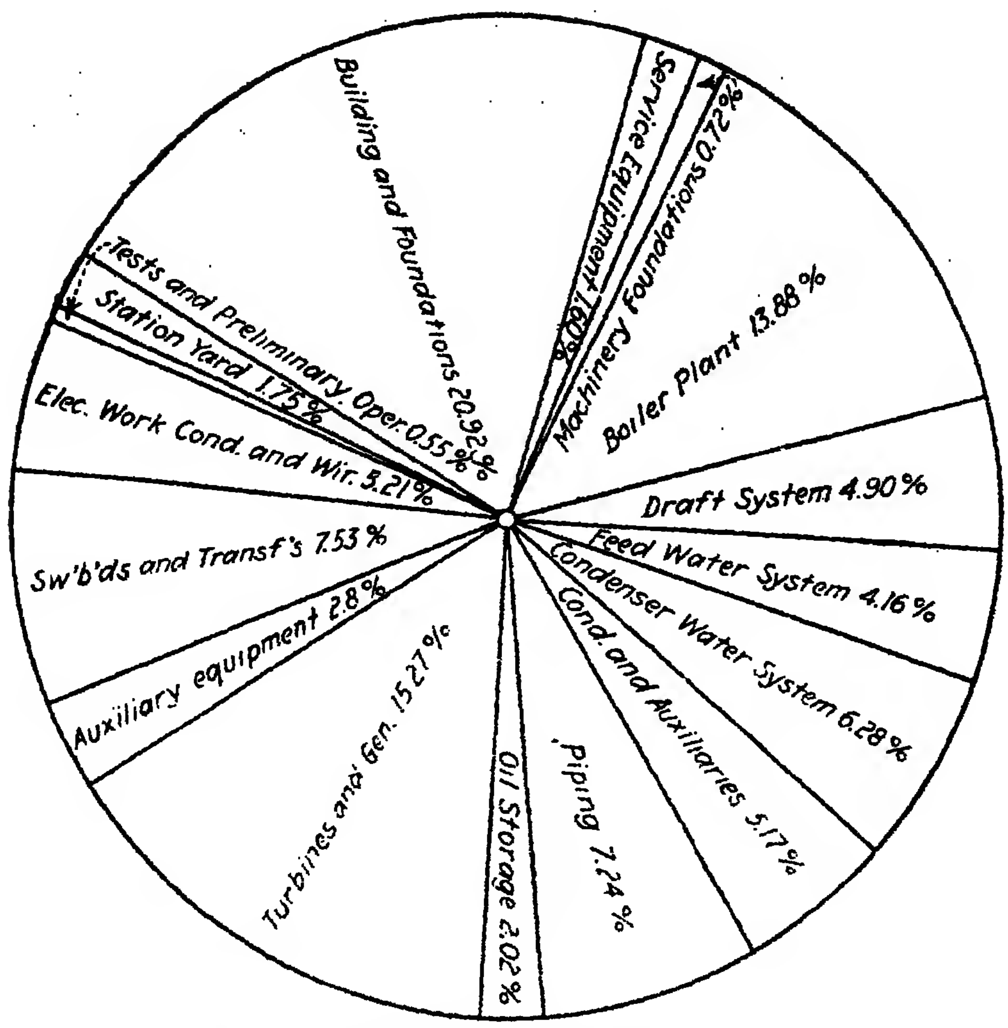

Fig. 21.—Cost diagram of the 70,000-kva. Seal Beach station of the Los Angeles Gas and Electric Company. Total investment cost approximates $85 per kilowatt.

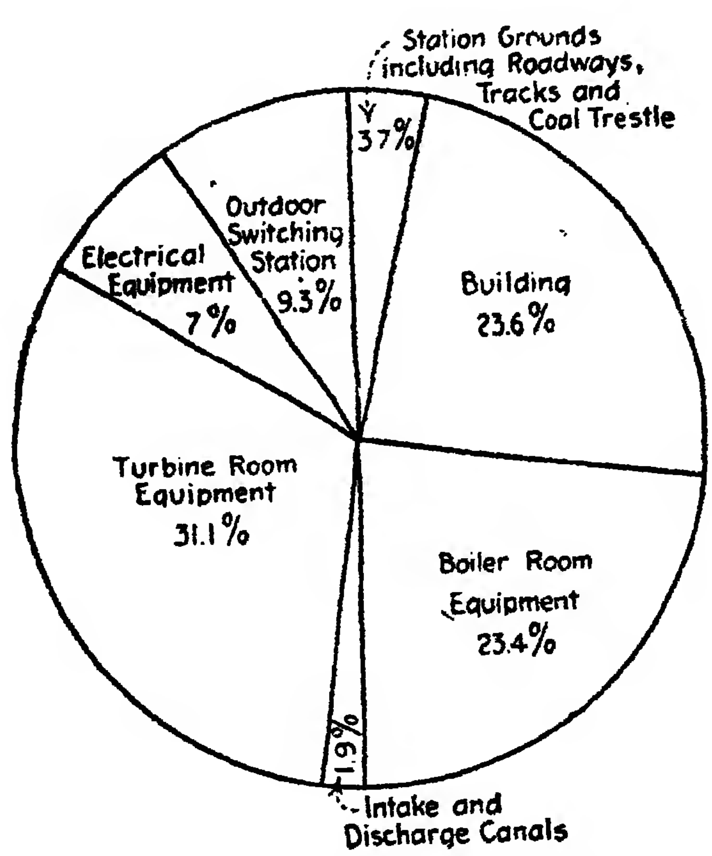

Fig. 22.—Cost diagram of the 70,000-kva. Devon station of the Connecticut Light and Power Company.

and fumes that may be present. The volume of air to be handled is small and the energy required for ventilating equipment is small. Care must be taken to keep the air at such a temperature that condensation does not occur, as this introduces an insulation hazard.

Cost of Buildings.—The cost of power station buildings is so variable that only average ranges can be given. In general, costs

TABLE IX.—DIVISION OF COSTS OF THE FIRST 200,000-KW. UNIT OF RICHMOND STATION OF THE PHILADELPHIA ELECTRIC COMPANY WITH 100,000-KW. INSTALLED

	Per Cent of Total Cost
Land	3.19
Piers and bulkheads	1.26
Dredging	1.16
Yard (fill, track, paving, planting)	1.33
Substructure	5.94
Intake and discharge tunnels and screening basin	9.65
Superstructure	26.13
Coal tower and conveyor structures	3.76
Coal-handling equipment	1.19
Boilers and stokers	10.86
Draft equipment, stacks, breechings, flues	1.39
Feed-water equipment	1.03
Boiler plant piping	5.44
Miscellaneous boiler plant equipment	3.17
Main and house turbo-generators and foundations	8.75
Condensers, auxiliaries and water system	3.04
Electrical equipment	10.99
Miscellaneous plant equipment	1.72
Total	100.00

are figured on both a square foot and a cubic foot basis. The plain power house made of brick or steel with concrete floors will cost from $4 to $4.75 per square foot of floor area or 10.0 to 20.0 cts. per cubic foot of interior volume. The cost of power houses of more pretentious character suitable for city installations and having good architecture will range from $6 to $6.50 per square foot of floor area or 20.0 to 40.0 cts. per cubic foot. Other costs connected with power houses are also variable and will be considered later. Hydro-electric stations, in particular, differ very much in costs because of differences in the cost of forebays, tunnels, penstocks, dams and spillways and must be considered as specific cases.

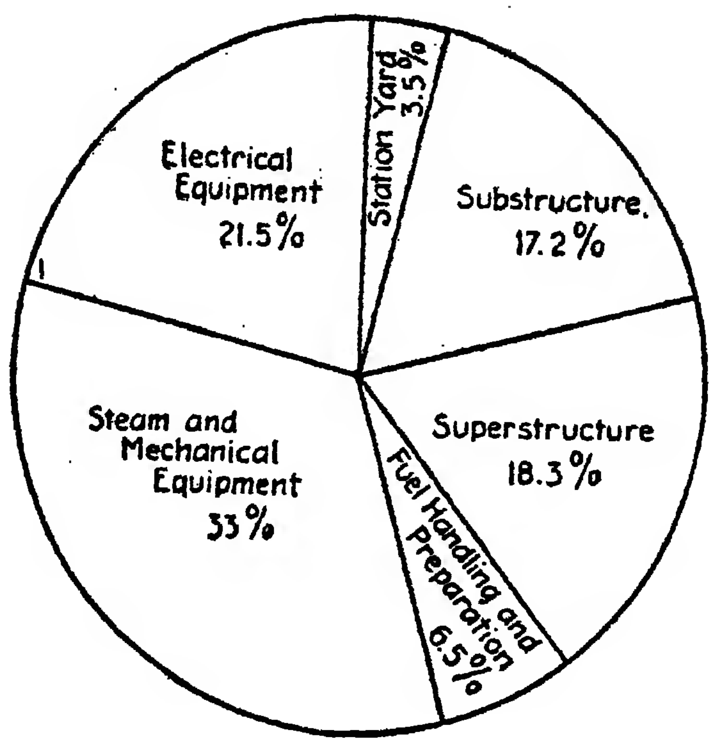

FIG. 23.—Cost diagram of the first and second section of the Cahokia station of the Union Electric Light and Power Company in St. Louis. 70,000 kw.

Items included in sectors are as follows:

		Per Cent
A.	Station yard	3.5
	Levees, railroad tracks, highway, concrete and riprap protection.	
B.	Substructure	17.2
	Complete below and outside of waterproofing membrane, including:	
	Machine foundations.	
	Raw coal and ash-handling yard structures.	
C.	Superstructure	18.3
	Complete above and within waterproofing membrane.	
D.	Fuel handling and preparation	6.5
	Track scale.	
	Car dump.	
	Coal-elevating and distributing equipment.	
	Crusher and breaker.	
	Pulverizing equipment.	
	Pulverized-coal weighing and transport system.	
	(Does not include any driving motors and controls).	
E.	Steam and mechanical equipment	33.0
	Boilers and superheaters.	
	Settings and furnaces.	
	Furnace control.	
	Draft system.	
	Feed-water system.	
	Condenser system.	
	Piping.	
	Auxiliary equipment.	
	Turbo-generators.	
	Ash-handling equipment.	
	(Does not include generator end of turbo-generators nor any driving motors and controls for mechanical equipment.)	
F.	Electrical equipment	21.5
	Station transformers.	
	Switch controls.	
	Storage batteries.	
	(Includes generator end of turbo-generator and all driving motors and controls.)	
G.	Prorated items.	
	Engineering and drafting.	
	Office at works.	
	Insurance.	
	Temporary construction.	
	Shrinkage on construction equipment.	
	Preliminary operation.	

Grounds.—The power station site should be amply large for present conditions and should provide some room for future expansion. Walks, shrubbery and lawns are attractive features surrounding a station and should be provided if possible at a reasonable cost. The complete site should be surrounded with a

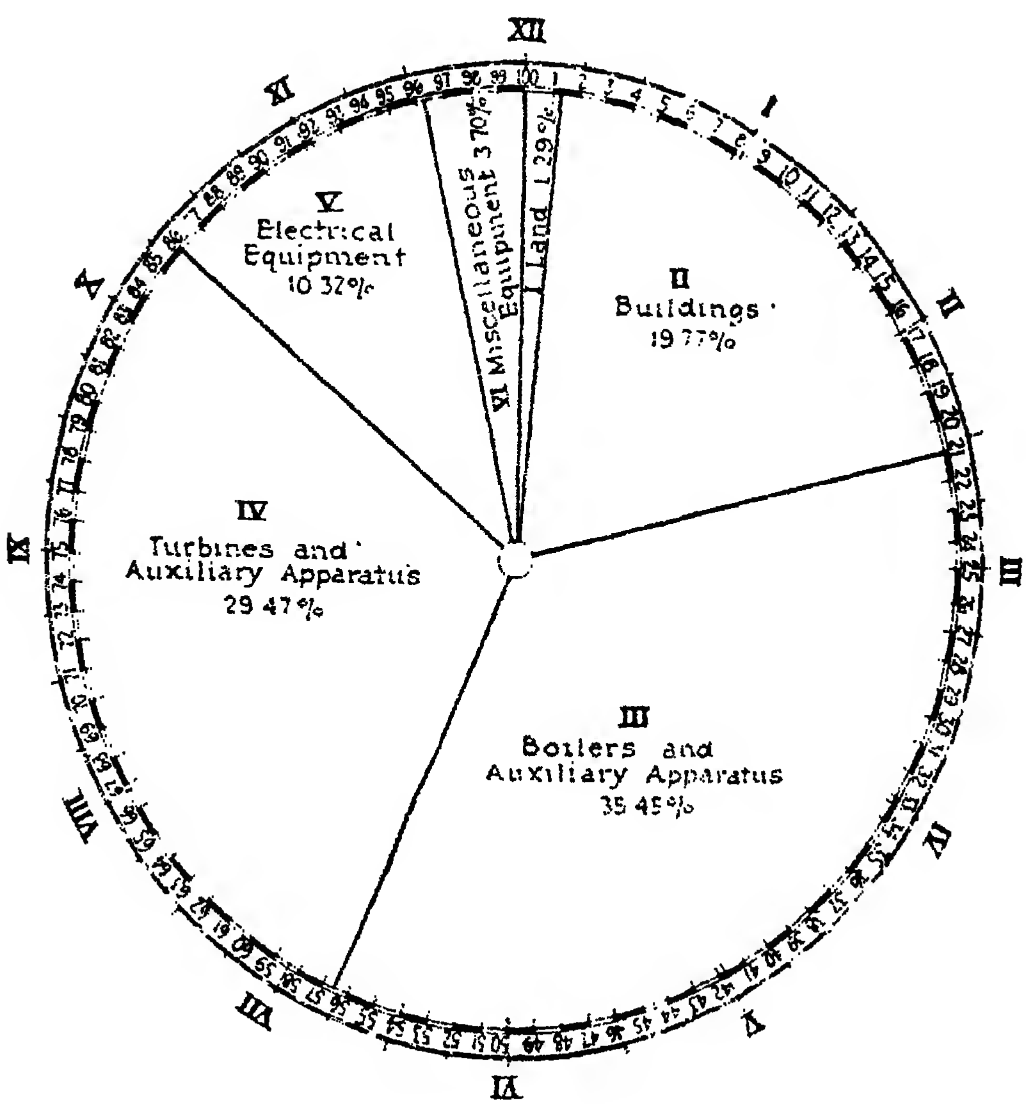

FIG. 24.—Division of costs in the Tulsa station of the Oklahoma Power Company. 30,000 kw.

General construction expenditures, such as engineering and supervision, construction office expenditures, transportation of workmen, construction storeroom expense, are distributed pro rata among the six subdivisions: (I) Land includes first cost of land, roads, beautifying grounds, protection of river bank. (II) Buildings include substructure and superstructure, machine foundations, pump houses, intake house, discharge well, concrete work at spray ponds, coal crane runway, structural steel. (III) Boilers and auxiliary apparatus include boilers, furnaces, economizers, draft fans, flues and stacks, fuel-handling and storage equipment, oil burners, pumps, stoker, evaporator, water-treating plant, all station piping. (IV) Turbines and auxiliary apparatus include turbines, generators, exciters, condensers and auxiliaries, traveling and stationary screens, spray ponds. (V) Electrical equipment includes switchboards, switches, meters, conduit wires and cables, battery. (VI) Miscellaneous equipment includes cottages for employees, machine tools, turbine room crane, automobiles and trucks for operation (but not construction).

metal fence, as this is cheapest to maintain and most satisfactory from an investment and service standpoint. The grounds should always be kept clean and free from débris, as appearances count a great deal with the public and react favorably on the morale of the employees.

CHAPTER IV

FUELS, FUEL HANDLING AND ASH HANDLING

For producing steam various fuels are available, which may be classed as:

1. Solid.
2. Liquid.
3. Gaseous.

A station may be equipped to burn any of these types of fuel or combinations and local conditions govern the practices. In oil fields, for example, depending on market price and available supply, plants may burn either coal, oil or gas as desired. In most plants, however, coal is used as the standard fuel and oil or gas only where special conditions make them economical or available.

Coal.—Of the solid fuels, many classifications exist ranging through anthracite, semi-bituminous, lignite, peat and several specially prepared or processed fuels. Bituminous coal is the dominant fuel for producing steam because of its lower cost, its widespread occurrence and its availability in large amounts. But a decided difference occurs in the quality of the coal in the different territories, so that equipment for utilizing the fuel must be adapted to the supply available. Different types of stokers, chain grates or pulverized-fuel equipments have certain ranges of application depending on the fuel analyses.

Anthracite coal is used in a few instances where plants are located near the mines. Lignite and peat are little used in this country because, at present prices, they cannot compete with bituminous coal. In Germany, however, much pioneer work has been done in burning these fuels and experience shows they can be used successfully.

Thus the production of electricity in this country by steam stations is brought about very largely by the consumption of about 40,000,000 tons of bituminous coal each year. And fuel supply is a very important item in the industry. Some companies have gone so far as to purchase coal mines, particularly when

plants may be located conveniently near the mines, but the larger number purchase most of their coal on a contract basis and buy the remainder on the open market.

Fuel Specifications.—An ideal coal contract should contain the following clauses:

1. Period of operation of contract, conditions for cancellation and rate of delivery.

2. Definite specification of the mine or mines from which the fuel will be supplied. Also a typical proximate analysis, ash-fusing temperature and B.t.u. in coal as shipped. Also it may be advisable to specify the type of equipment in which shipments are to be made.

3. Definite price per ton for a basic quantity of fuel per week with provisions for additional tonnage if required at a price to be determined by specific conditions.

4. Standard quality of coal with provisions for price adjustments for coal better or worse than the standard. Particulars of test methods and details of guaranteed specifications for the coal. Ash content is the easiest and most convenient method for securing price adjustments and the sampling and analyzing should be made in accordance with the practice recommended by the A.S.T.M.

5. Provisions for precedure if deliveries are interrupted, terms of payment and provision for price adjustments should conditions change materially.

6. Arbitration of controversial questions should be provided, as the buyer and seller may disagree on certain points.

These clauses must be adapted to local conditions and to the purchase of bituminous or semi-bituminous run-of-mine, bituminous slack, screenings, washed slack, anthracite steam sizes or other fuels. It is very difficult to make any contract apply to emergency conditions, but the public utility must exercise every precaution to maintain its fuel supply under all conditions.

Processed fuels for central stations and the use of by-product distillation plants have been discussed and some experimentation has occurred. National conservation of natural resources makes such attempts worth while, but the fact remains that the overall economy is in favor of the present practices in fuel burning. Future developments, however, may warrant the installation of by-product plants as adjuncts to large power stations.

Fuel Oil.—The United States produces about 500,000,000 bbl. of crude oil yearly and about 13,000,000 bbl. are burned in power stations of all types. Price differentials and fluctuations as compared to coal prevent its greater use in power plants. Diesel plants have been used successfully in small stations, but there has been little popularity for the Diesel engine in large stations in this country up to the present time.

Fuel oil is delivered on a volume basis with a gage, stick, plumb line or other mechanical method of measurement; 60°F. is taken as standard, and a corrective temperature coefficient is 0.0004 per degree Fahrenheit. The oil should be purchased on a specification basis as to B.t.u. content and proximate analysis and the contract should contain delivery provisions, price provisions and provisions for handling analyses and price corrections.

Residue from refineries and tar have been burned successfully under boilers but no great use is made of these fuels.

Gas Fuels.—Natural gas, producer gas, blast-furnace gas and coke-oven gas are all used to a limited extent under boilers. Natural gas occurs only in certain localities and is limited in amount, the other gases are used chiefly in local manufacturing plants, such as steel mills. Gas and oil, although very satisfactory as fuels, appear to have no prospect of very extensive applications in central stations, although the development of by-product plants may offer more opportunity for the use of gas in power stations.

Coal Purchases.—Coal purchases should be based on producing energy at the lowest cost rather than on the basis of the greatest B.t.u. content per dollar. The handling of the fuel, the firing equipment, the labor and the investment charges should all be considered. Among the factors are:

1. Cost of coal delivered into the furnaces.
2. Cost of coal-handling and ash-handling machines, crushers and buildings.
3. Cost of handling ash and disposing of it.
4. Cost of labor and combustion equipment in securing proper combustion with coals of different types.
5. Cost of preventing slagging, clinkering or other operating troubles.

For many reasons a satisfactory coal should have a volatile content less than 20 per cent, as little ash as possible, an ash-fusing temperature not less than 2450°F. and should be capable

of storage for long periods without trouble from spontaneous combustion. After general considerations have been used to determine the field of choice of fuels, it is possible to decide on the specific fuel for use with stokers by using the ash content as the determining element. E. B. Ricketts[1] has proposed a formula for determining this condition on the basis of comparing any coal to a standard coal having 5 per cent ash. Figure 25 shows curves which are useful in the solution of the problem. The ratio of the maximum capacity of the boiler plant with 20 per cent ash in the

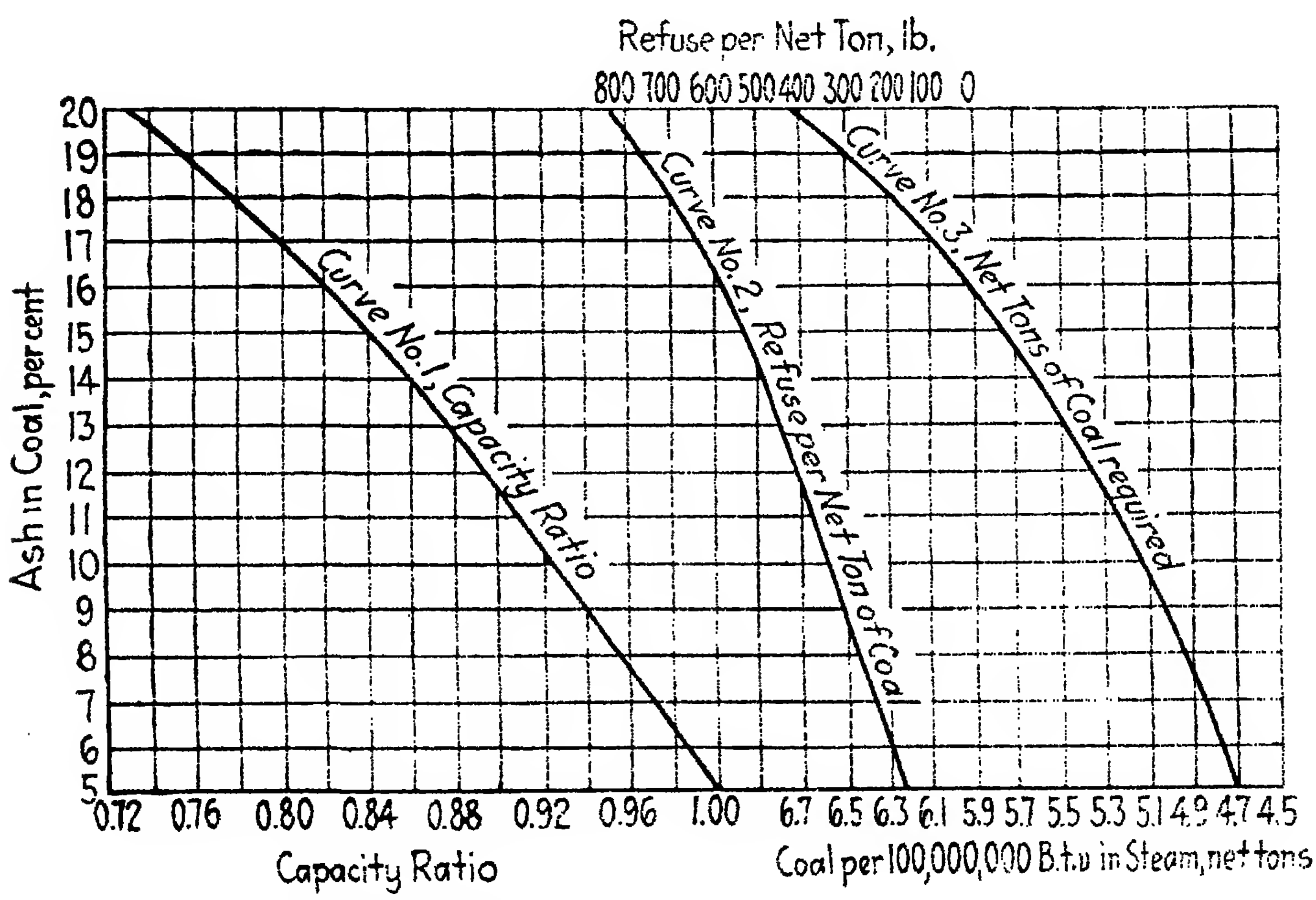

FIG. 25.—Chart for determining the cost of coal on the basis of ash content. (*E. B. Ricketts, A.S.T.M.*, 1922.)

coal to the capacity when using coal with 5 per cent ash is called the capacity ratio (curve 1). The pounds of refuse per ton from x per cent ash coal is given by curve 2. Curve 3 shows the tons of coal with x per cent ash to produce 100,000,000 B.t.u. in steam. No account is taken of difference in labor costs, as these are small items. The data are experimental and based on plants in New York and Cincinnati and represent averages for an underfeed stoker plant.

Two sets of formulas are prepared for applying these curves to all conditions. The first set takes into account the relative coal cost of a given number of B.t.u. in the steam plus the cost of ash handling and removal, and the second set, in addition to the items

[1] A.S.T.M., 1922.

considered in the first set, takes into account the extra investment in boiler plant to burn the high-ash coal. At maximum rating, 3,000 boiler hp. will produce 100,000,000 B.t.u. in steam per hour. If the boiler plant, including land, building, etc., cost \$100 per maximum horsepower when using 5 per cent ash coal, then

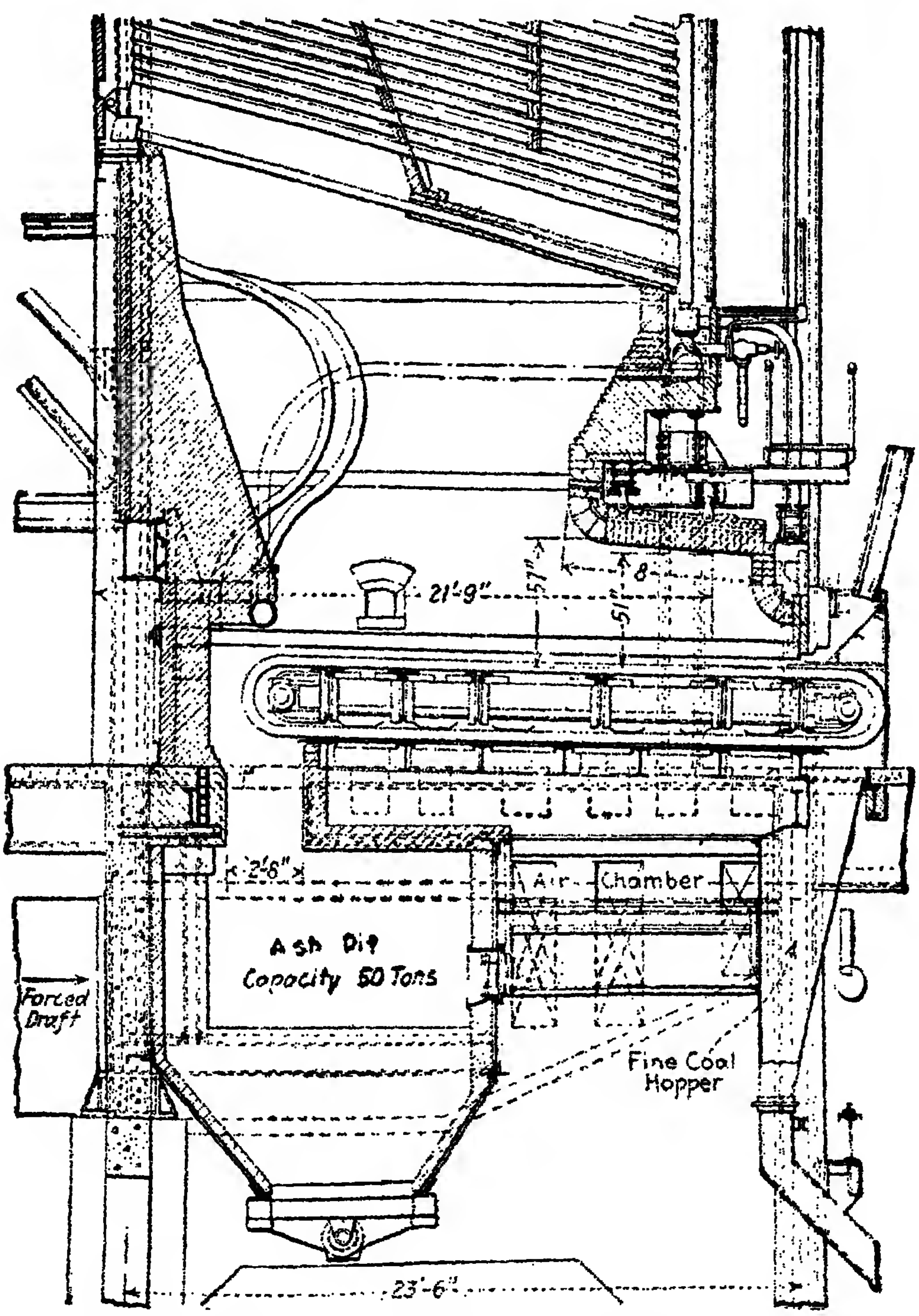

FIG. 26.—A modern stoker in the Calumet station of the Commonwealth Edison Company. The stoker is 24 ft. wide, 18 ft. 3 in. long and burns 35 lb. of Illinois coal per hour per square foot of grate surface to maintain 240 per cent rating on a B. & W. boiler having 10,089 sq. ft. of heating surface. The furnace volume is 11.8 cu. ft. per square foot of grate surface. The stoker has a maximum rating of 55 lb. of coal per square foot of grate surface.

the total cost would be \$300,000, which at 15 per cent overhead charge equals \$45,000 per year, or \$5.13 per hour.

Let X = cost in dollars per net ton of 5 per cent ash coal in bunkers (exclusive of ash handling).

Y = value in dollars per net ton of x per cent ash coal in bunkers (exclusive of ash handling).

A = load factor = $\dfrac{\text{total steam generated per year}}{\text{steam generated at maximum hour} \times 8{,}760}$.

B = cost of boiler plant per maximum horsepower divided by 100.

C = tons of 5 per cent ash coal to produce 100,000,000 B.t.u. in steam (4.67) (curve 3).

D = tons of x per cent ash coal to produce 100,000,000 B.t.u. in steam (curve 3).

R = capacity ratio (curve 1).

S = pounds of refuse per ton from x per cent ash coal (curve 2).

T = pounds of refuse per ton from 5 per cent ash coal (160 lb.) (curve 2).

U = cost of ash handling and removal in dollars per pound.

Then, neglecting investment,

$$Y = CX/D.$$

$$Z = Y - (S - T)U.$$

If investment is considered also,

$$Y = \frac{CX + (5.13B/A) - (5.13B/AR)}{D}.$$

$$Z = Y - (S - T)U.$$

Example.—When 5 per cent ash coal costs $3 per ton in the bunkers, ash handling and removal costs 20 cts. per ton, the load factor is 50 per cent and additional boiler plant would cost $90 per maximum horsepower with 5 per cent ash coal, to determine the economic limit of cost for 20 per cent ash coal.

$$X = \$3,\ A = 0.50,\ B = 0.90,\ C = 4.67$$

$$D = 6.75 \text{ (curve 3)},\ R = 0.736 \text{ (curve 1)}$$

$$S = 840,\ T = 160 \text{ (curve 2)},\ U = 0.0001$$

then

$$Y = \frac{4.67 \times 3 + \dfrac{5.13 \times 0.90}{0.50} - \dfrac{5.13 \times 0.90}{0.50 \times 0.736}}{6.75} = \$1.59$$

$$Z = 1.59 - [(840 - 160) \times 0.0001)] = \$1.52$$

Coal Handling.—The size of station, the reliability of coal deliveries and the location of the station have an important bearing on coal arrangements. It is advantageous to have both rail and water transportation facilities for fuel but the larger number of stations rely on rail deliveries only. A few companies own their own rolling stock or barges but the larger number receive the fuel in the equipment owned by the transportation companies.

The quantity of coal that is necessary in storage in order to care for seasonal deliveries, strikes or other emergencies is determined by many conditions. A great sum of money is tied up in fuel

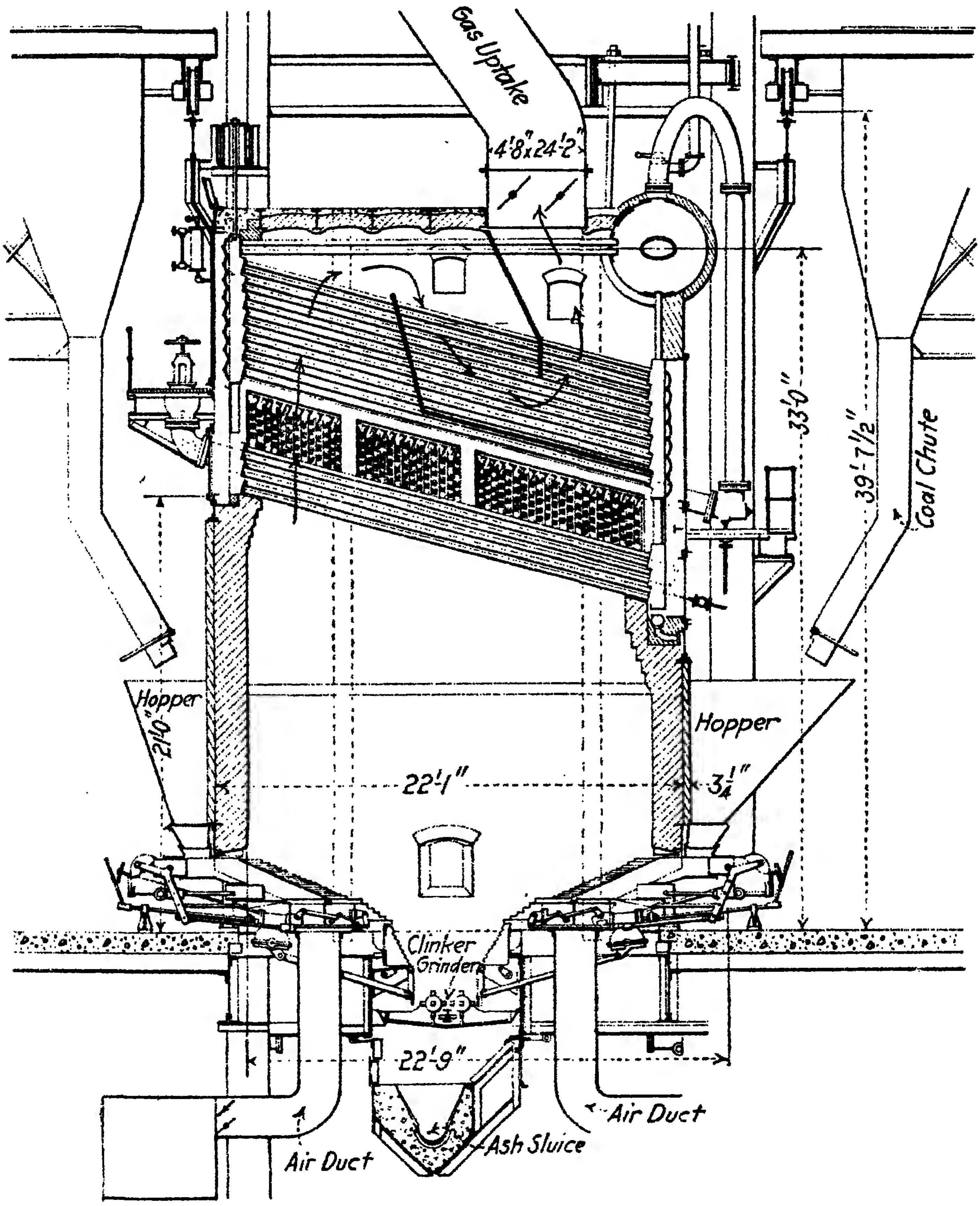

Fig. 27.—Cross-section of boilers in the Hell Gate station of the United Electric Light and Power Company. The boilers are cross-drum type with 18,900 sq. ft. of heating surface and are double fired with Taylor stokers. At the bottom of the ash pit are two clinker guider rolls, the tops of which move outward to crush the clinkers against two hinged crusher plates. The ash falls into the inclined trough and is sluiced to a central ash pit outside the station.

storage, yet the fuel supply must be guaranteed so that even mouth-of-mine stations use outdoor storage. From 3 to 9 months' fuel supply in storage is the customary range of storage

supply. If land values are high, deliveries reliable and the station large, a smaller quantity is held in storage than when plants are located in the country and have poor delivery facilities. Preferably, coal should be stored adjacent to the plant, but local conditions often prevent this practice and the coal storage yard is located at some distance from the plant.

Coal storage introduces a hazard due to spontaneous combustion and care must be exercised to care for this condition. Some plants have gone so far as to use underwater storage. Bulletin

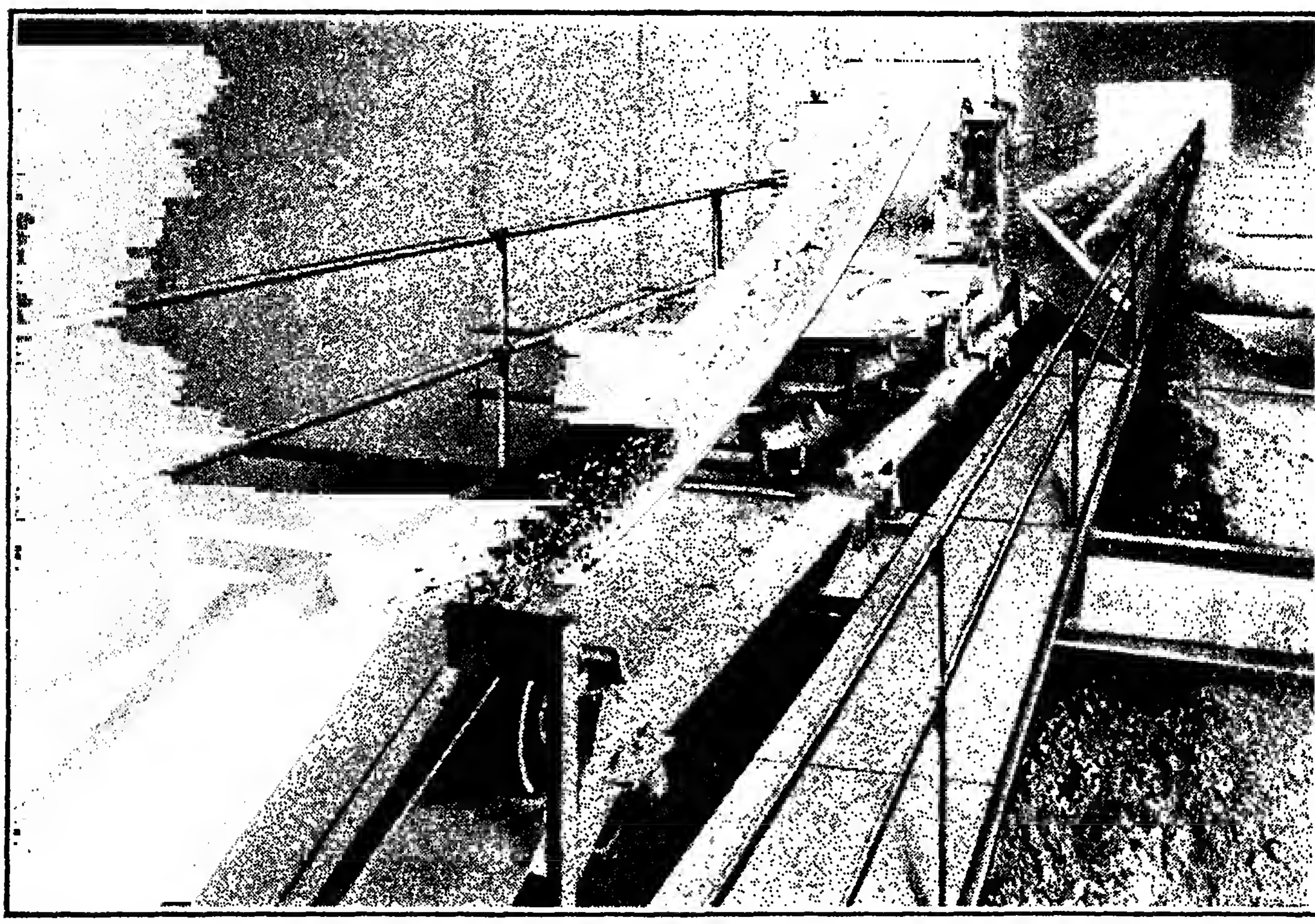

FIG. 28.—A belt conveyor is frequently used with tripping device for distributing coal to bunkers.

116 of the Illinois University Experiment Station gives an authoritative treatment of spontaneous combustion of fuels. Also coal storage introduces added elements of cost because of a greater amount of fuel handling and because of slacking, freezing and other occurrences. Yet these costs may be offset by price differentials granted by the coal producers for seasonal purchases and by questions involving service reliability.

The larger stations with rail delivery of coal generally favor the use of car dumpers for unloading coal, but locomotive and bridge cranes with grab buckets are found at many plants. In storage yards locomotive and bridge cranes with grab buckets are used to store the coal and to place it in cars or on conveyors for use at

the power station as wanted. Locomotive cranes, bridge cranes, tractors with drag line buckets and belts are used to spread coal in the storage yards.

Cars are cheaply unloaded by dumping them into track hoppers whence the coal may go to a crusher or to the storage yard. Coal from the crusher is usually conveyed by belts on horizontal planes and by bucket conveyors on a vertical plane to the boiler room. In some cases, a coal tower with a grab bucket raises the coal to the top of the boiler plant from which it goes by gravity through the crusher and to the distributing conveyors or cars in the boiler house. The object to be attained is to get the most economical and most reliable delivery of coal to yard or to

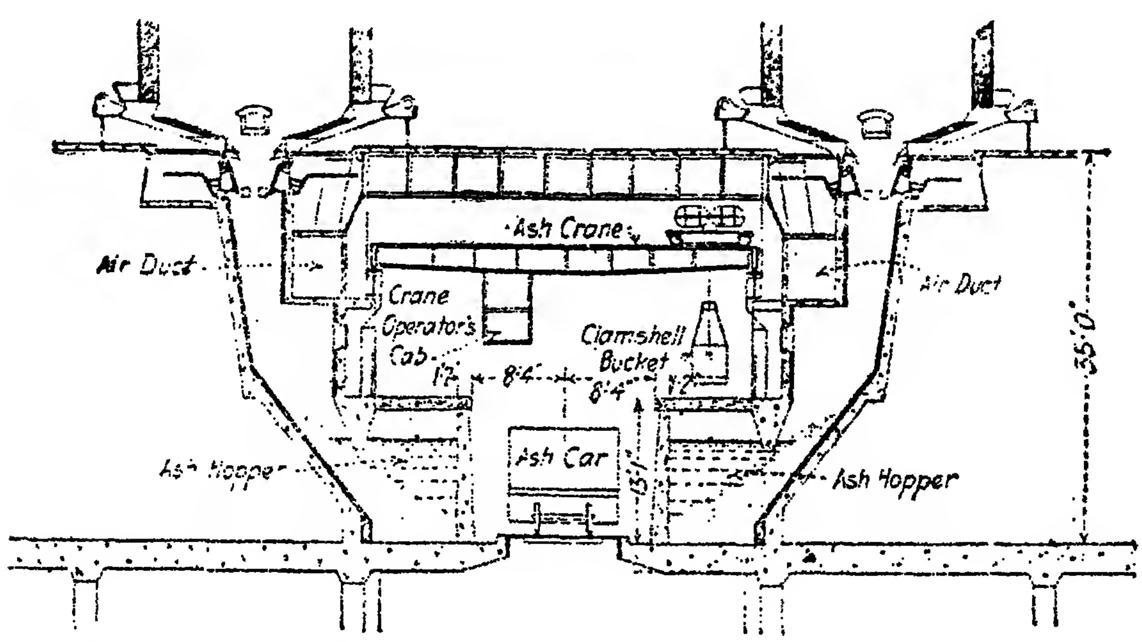

FIG. 29.—Water-sealed ash pit of the Springdale station of the West Penn Power Company.

boiler room. The shortest distance possible and a direct route are desirable features.

When barge coal is available, the grab bucket and coal tower are commonly used. A modern installation of this character is found at the Richmond station of the Philadelphia Electric Company. A coal tower is equipped with two hoists of 325 gross tons per hour capacity. The coal passes from the hoist bucket to grizzly screens then to picking tables and crushers with the equipment arranged with two-way hoppers so as to take the uncrushed coal to any desired crusher and the crushed coal to the desired belt conveyor. The coal may also be by-passed from the hoist directly to the belt conveyors if this is desired. The main belt conveyors pass over weightometers at the coal tower and then to the conveyor bridge in fireproof compartments

and thence to duplicate sets of cross-conveyors over each row of bunkers.

Stations using pulverized fuel handle coal directly from cars, barges or storage yard by conveyors, buckets or hoists to the coal preparation plant. In order to eliminate metal pieces and prevent injury to the pulverizing mills a magnetic separator is usually inserted on a belt conveyor.

The coal may be weighed in several ways—railroad weights may be taken, weighing hoppers may be located at the exit from

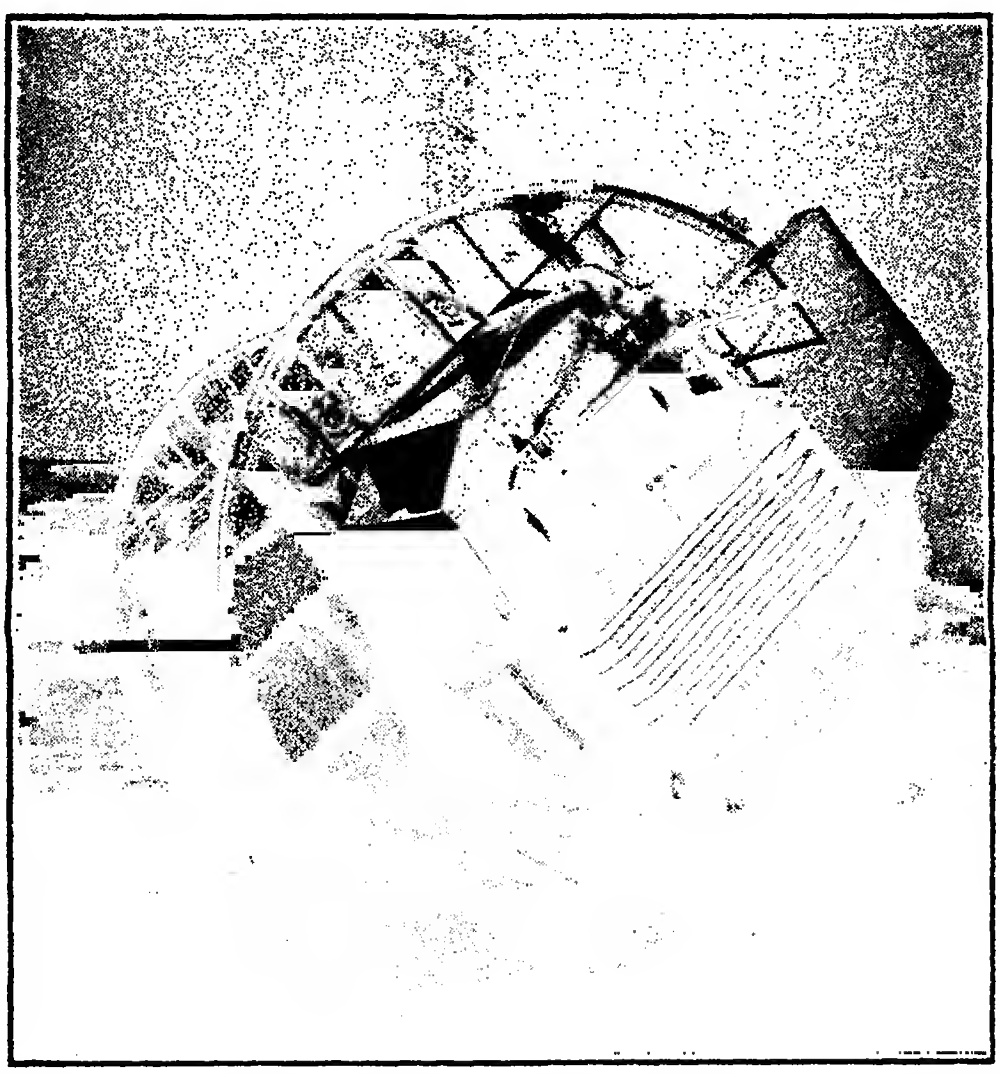

Fig. 30.—A gondola car dumper in operation at the Cahokia plant of the Union Electric Light and Power Company.

the crusher, car scales may be installed, conveyor scales may be used or automatic weighing may be done with the coal lorry.

Two typical and much favored installations are:

1. A low-hoist grab bucket coal tower near the building containing crusher and scales, from which the fuel goes by belt conveyors to the station and is carried by bucket elevators to the top of the building and thence is distributed to the bunkers by a belt conveyor and automatic tripper, or a cable car.

2. A high-hoist tower equal to the height of the station containing crushers and scales from which the coal is delivered by gravity to belt conveyors or cable cars for bunker distribution.

The belt conveyors operate at speeds from 300 to 450 ft. per minute and the bucket elevators at 100 to 200 ft. per minute. Belt conveyors cost from $2 to $3 per inch width per foot length while bucket conveyors cost from 4 to 5 cents per ton capacity per hour per foot length. Empirical formula have been devised for determining the energy consumption of conveyors and elevators.[1]

When the fuel is dirty and poor in quality but low in price, as in some plants using anthracite "fines," a washer installation is

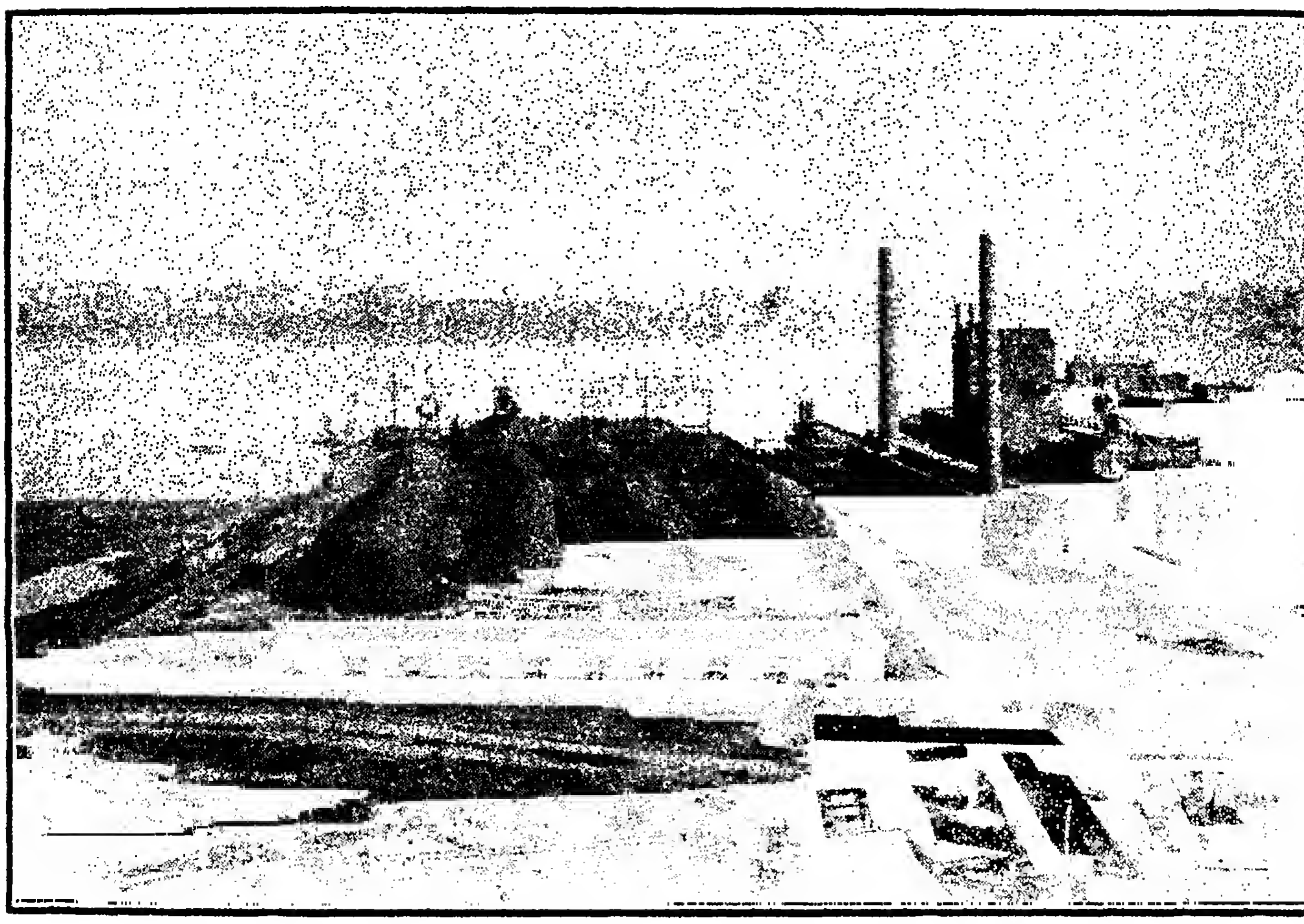

FIG. 31.—Modern coal storage yard on the Hudson River.

found to be profitable, as the washed coal can be burned with less trouble due to dirt and with a higher combustion efficiency.

Sampling of the coal upon delivery should be followed and great care must be exercised in securing a representative sample of the shipment. At least 1,000 lb. of fuel should be selected for the first sample and this should contain a representative amount of large and small sizes. A good coal laboratory is needed to secure accurate results in coal testing, and standardized sampling and testing methods should be followed.

Useful Formula.—In making heat computations for fuels, a fundamental formula is useful which gives the theoretical air requirements to burn 1 lb. of coal:[2]

[1] See "Standard Handbook," 5th ed., p. 736.

[2] U. S. Bureau of Mines.

$$W = 0.1158C + 0.3448H - 0.04336(O - S),$$

where W = pounds of air per pound of fuel.
C = percentage of carbon, ultimate analysis.
H = percentage of hydrogen, ultimate analysis.
O = percentage of oxygen, ultimate analysis.
S = percentage of sulphur, ultimate analysis.

Another simpler formula gives the heat value of coal from a proximate analysis.[1]

$$\text{B.t.u.} = 14{,}544C + 27{,}000V\left[1 - \left(\frac{1}{\frac{C}{V} + 0.5}\right)\right],$$

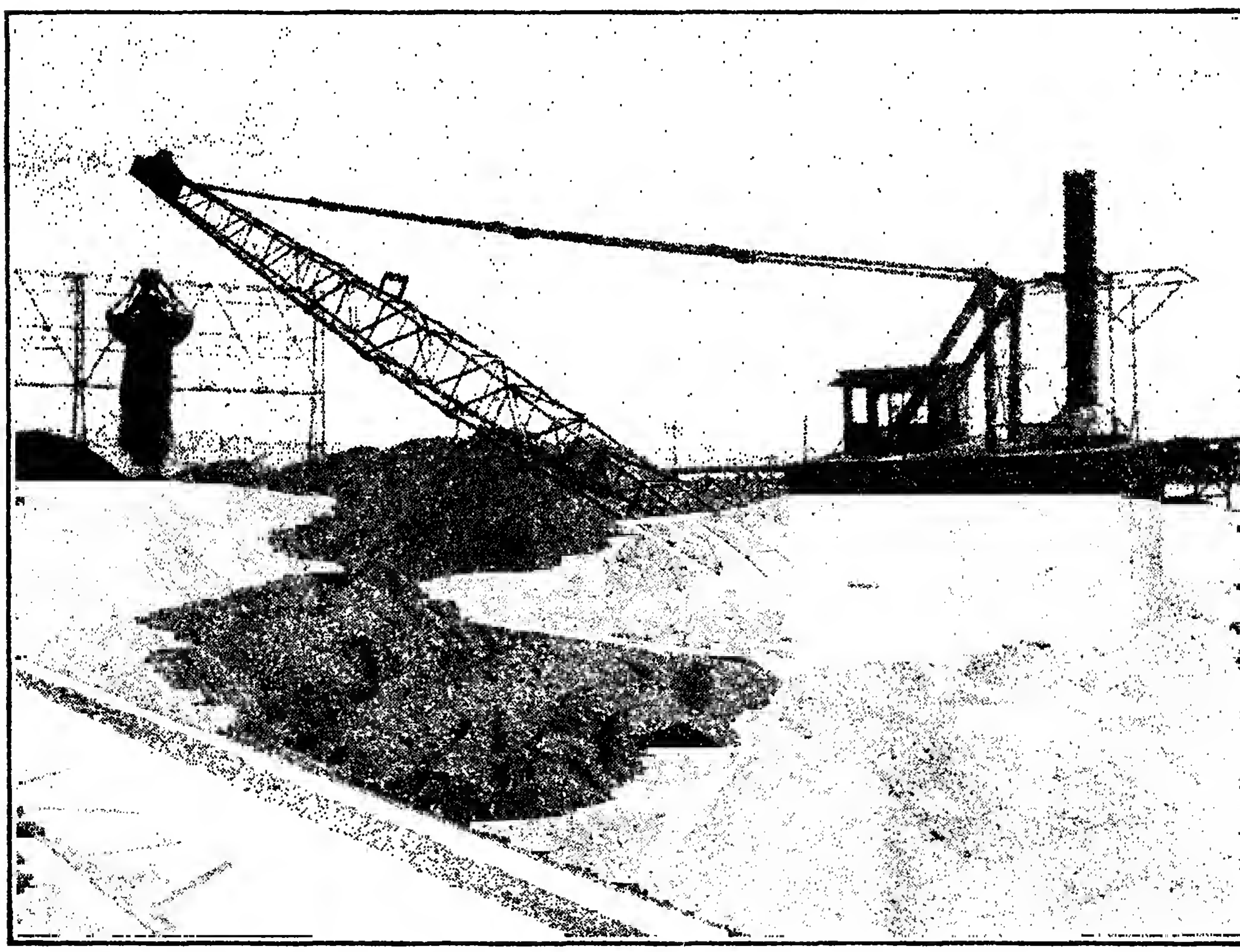

Fig. 32.—Clam shell and crane on temporary tracks for handling coal in a storage yard.

where C and V are the fractional weights of fixed carbon and volatile respectively in the coal, and the heat value from the ultimate analysis is:[2]

$$\text{B.t.u.} = 14{,}544C + 62{,}028\left(H - \frac{O}{8}\right) + 4{,}050S,$$

where C, carbon; H, hydrogen; O, oxygen; and S, sulphur are the fractional parts in 1 lb. of coal.

[1] Locke.
[2] Dulong.

Pulverized Coal.—Several plants have used pulverized coal under boilers recently. In most cases a major reason for this was because poor coal was available or because coal having different characteristics was used at different times. Other flexible features connected with the burning of powdered fuel, such as bringing up boilers, eliminating banking losses and getting quick responses to load changes, have also proved advantageous. The inherent conditions of efficiency in burning fuel under boilers, with either pulverized fuel and stokers is about the same with equipment adapted to the installation, and the fuel used and local fuel conditions and local operating conditions usually determine whether to use stokers or pulverized fuel. Both types of equipment are being improved from year to year.

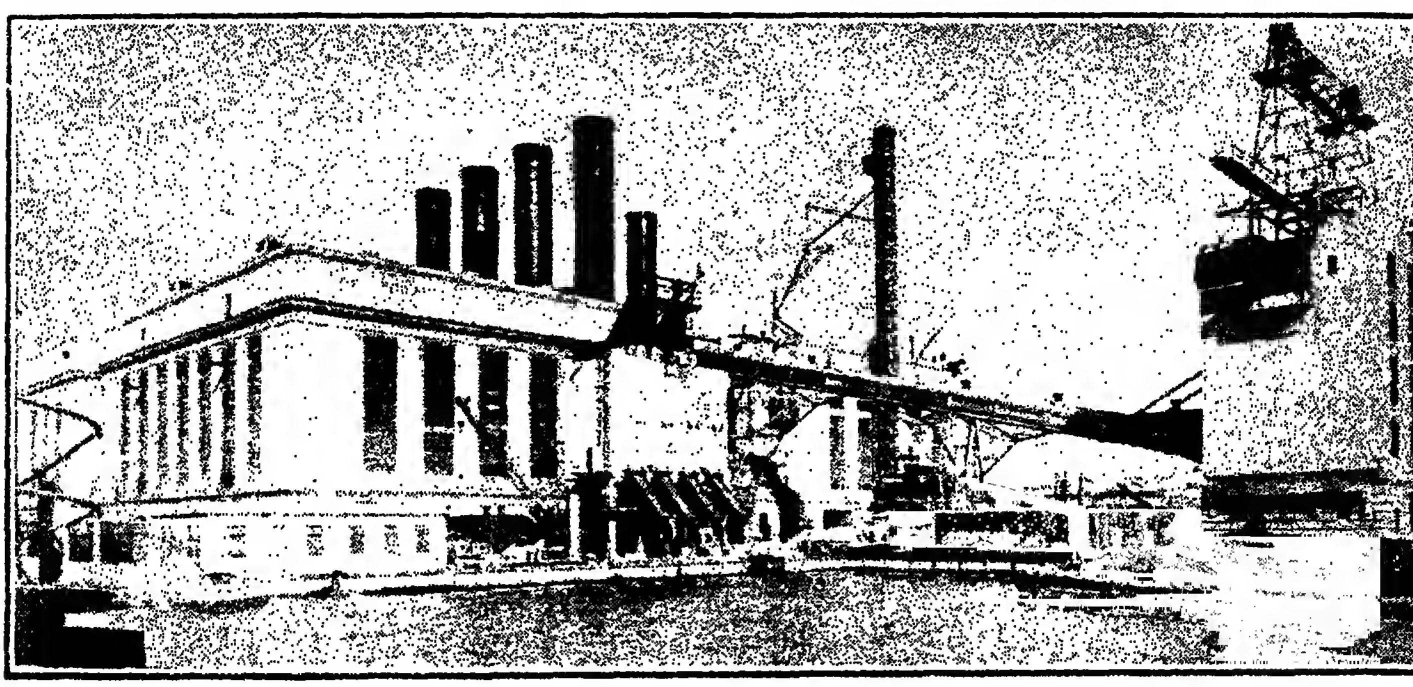

Fig. 33.—A coal tower and an ash tower are favored by the Philadelphia Electric Company at the Delaware station.

The pulverized-fuel equipment is of two general types, called the "bin system" and the "unit system." In the bin system a central preparation house is used and bins are used to store the pulverized fuel after it is prepared and before it is used. This system usually requires a coal preparation plant as a separate building installation either inside of or adjacent to the boiler room proper. The advantage of this system is that a fuel reservoir, so to speak, is interposed between the coal preparation plant and the boilers, so that a certain reserve is maintained. The disadvantage is that more equipment is used, greater space is required, and thus the investment cost is usually larger.

The unit system involves the use of a preparation plant for each boiler and direct firing of the fuel as it is prepared. A

TABLE X.—COMPOSITION AND HEAT VALUE OF UNITED STATES COALS[1]

County, bed or local name	Proximate analysis "as received"				Ultimate analysis "as received"					Heat value, B.t.u. per pound "as received"
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Alabama:										
Bibb, Belle Ellen	3.16	31.05	59.56	6.23	1.20	5.33	78.28	1.37	7.59	14,141
Jefferson, Dolomite	3.16	25.40	67.75	3.69	0.56	5.05	82.28	1.36	7.06	14,616
Jefferson, Littleton	2.53	26.94	59.48	11.05	0.79	4.80	74.44	1.59	7.33	13,286
St. Clair, Davis (Tillman Station)	3.39	30.69	57.08	8.84	2.34	5.18	73.81	1.53	8.30	13,363
Shelby, Straven	3.83	32.03	58.66	5.48	0.97	5.29	77.26	1.25	9.75	13,799
Tuscaloosa, Avernant	2.62	24.18	64.11	9.09	0.64	4.72	77.52	1.48	6.55	13,729
Alaska:										
Alaska Peninsula, Chignik Bay, Thompson Valley	10.77	30.37	43.99	14.87	0.70	4.98	55.27	0.61	23.57	9,641
Bering River, Hartline	4.75	13.72	63.31	18.22	0.62	3.14	65.93	1.32	10.77	10,820
Cook Inlet, Port Graham	19.96	38.73	32.46	8.85	0.52	5.81	49.53	0.92	34.37	8,793
Matanuska, Matanuska River	1.72	24.36	58.97	14.95	0.46	4.46	70.78	1.42	7.93	12,585
Seward Peninsula, Chicago Creek	37.82	26.14	32.16	3.88	0.65	6.12	41.79	0.67	45.89	......
Arizona:										
Navajo, Oraibi	9.88	32.64	46.86	10.62	1.12	5.42	62.00	1.13	19.71	10,800
Arkansas:										
Logan, Paris	2.77	14.69	73.47	9.07	2.79	4.02	78.71	1.46	3.95	13,774
Pope, Russellville	2.07	9.81	78.82	9.30	1.74	3.62	80.28	1.47	3.59	13,702
Sebastian, Greenwood	3.21	14.84	72.66	9.29	3.12	3.75	78.37	1.52	3.95	13,588
California:										
Monterey, Stone Canyon	6.95	46.69	40.13	6.23	4.17	6.28	66.01	1.17	10.14	12,477
Colorado:										
Boulder, Lafayette	19.15	30.82	44.27	5.76	0.25	5.93	56.38	1.08	30.60	9,616
El Paso, Pikeview	26.20	29.67	37.67	6.46	0.30	6.13	49.36	0.66	37.09	8,352
Garfield, Newcastle	4.45	42.05	49.56	3.94	0.44	5.43	72.57	1.72	15.90	13,129
Montezuma, Cortez	3.89	37.01	46.58	12.52	7.04	4.96	66.19	1.16	8.13	12,341
Weld, Platteville	28.90	28.83	37.25	5.02	0.46	6.64	48.36	0.93	38.59	8,465
Georgia:										
Chattooga, Menlo	3.80	15.88	65.83	14.49	1.27	4.32	70.59	1.09	8.24	12,791
Idaho:										
Fremont, Hayden	11.45	37.24	47.01	4.30	0.54	5.94	68.09	1.40	19.73	12,094
Illinois:										
Clinton, [a]Germantown	11.35	34.62	40.63	13.40	4.76	5.41	57.36	1.05	18.02	10,733
Franklin, Zeigler	11.82	27.66	55.10	5.42	0.46	5.44	67.87	1.34	19.47	11,961
La Salle, [a]La Salle	12.39	36.89	41.80	8.92	3.92	5.85	61.29	1.00	19.02	11,399
Macoupin, [a]Staunton	13.54	35.69	40.03	10.74	4.03	5.71	58.69	0.95	19.88	10,807
Madison, Collinsville	12.70	36.36	41.47	9.47	3.67	5.81	60.91	0.99	19.15	10,989
Marion, [a]Centralia	9.95	34.76	42.06	13.23	3.87	5.25	59.64	1.04	16.97	10,960
Montgomery, Panama	13.31	33.62	41.34	11.73	3.75	5.19	59.07	0.95	19.31	10,548
St. Clair, [a]Shiloh	11.69	35.70	39.42	13.19	4.38	5.46	57.15	0.94	18.88	10,699
Saline, Harrisburg	6.01	32.37	54.32	7.30	1.66	5.27	71.63	1.34	12.80	12,793
Sangamon, [a]Auburn	16.00	32.41	37.82	13.77	4.05	5.55	53.89	0.91	21.83	9,940
Williamson, Carterville	9.18	27.30	55.40	8.12	0.90	5.10	68.45	1.14	16.29	12,015
Williamson, Herrin	8.80	29.85	53.83	7.52	1.13	5.08	68.70	1.33	16.24	12,222
Indiana:										
Clay, [a]Brazil	16.91	26.85	38.87	17.37	1.89	5.48	52.97	1.01	21.28	9,524
Greene, [a]Linton	13.58	32.07	46.20	8.15	0.91	5.65	63.53	1.42	20.34	11,419
Knox, [a]Bicknell	12.08	32.48	44.42	11.02	3.65	5.34	60.45	0.89	18.65	11,011
Parke, [a]Rosedale	10.72	39.29	41.42	8.57	3.83	5.86	63.48	1.16	17.10	11,767
Pike, [a]Littles	11.12	36.98	42.55	9.35	3.78	5.63	63.01	1.13	17.10	11,549
Sullivan, Dugger	13.48	32.51	48.38	5.63	1.09	5.94	66.01	1.49	19.84	11,788
Vigo, [a]Macksville	12.82	34.80	42.08	10.30	3.27	5.66	61.16	1.03	18.58	11,119
Warrick, Elberfeld	9.69	38.59	41.04	10.68	4.79	5.39	62.36	1.28	15.50	11,412
Iowa:										
Appanoose, [a]Centerville	14.08	35.59	39.37	10.96	4.26	5.57	58.49	0.90	19.82	10,723
Lucas, [a]Chariton	15.39	30.49	41.49	12.63	3.19	5.74	55.81	1.14	21.49	10,242
Polk, [a]Altoona	13.88	36.94	35.17	14.01	6.15	5.52	54.68	0.84	18.80	10,244
Wapello, [a]Laddsdale	8.24	30.74	45.02	16.00	5.03	4.81	59.82	0.94	13.40	11,027
Kansas:										
Cherokee, [a]Scammon	2.50	33.80	51.25	12.45	5.68	4.91	69.07	1.20	6.69	12,900
Crawford, Fuller	4.85	33.53	52.52	9.10	4.95	5.08	71.20	1.24	8.43	12,942
Leavenworth, Lansing	11.10	35.51	40.69	12.70	3.99	5.30	60.72	1.13	16.16	11,065
Linn, [a]Jewett	9.04	29.69	45.55	15.72	3.72	5.01	60.99	1.06	13.50	11,142

[1] U. S. Bureau of Mines. [a] Samples from car delivers; all others are mine samples.

TABLE X.—COMPOSITION AND HEAT VALUE OF UNITED STATES COALS.[1]—(*Continued*)

County, bed or local name	Proximate analysis "as received"				Ultimate analysis "as received"					Heat value, B.t.u. per pound "as received"
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Kentucky:										
Johnson, Flambeau	2.36	48.40	38.75	10.49	1.20	6.47	71.98	1.16	8.70	13,770
Muhlenberg, Central City	8.73	37.76	45.93	7.58	2.65	5.52	67.65	1.42	15.18	12,208
Ohio, McHenry	9.89	35.94	43.36	10.81	3.64	5.37	62.27	1.33	16.58	11,392
Pike, Hellier	3.73	30.01	59.42	6.84	0.56	5.07	76.30	1.06	10.17	13,649
Webster, Wheatcroft	6.29	31.97	54.13	7.61	1.35	5.49	69.78	1.37	14.40	12,874
Maryland:										
Allegany, Eckhart	2.70	14.50	74.00	8.80	1.00	4.44	79.21	1.69	4.86	13,910
Allegany, Frostburg	3.20	14.50	75.60	6.70	0.92	4.51	80.99	1.77	5.11	14,100
Allegany, Lord	2.26	16.05	75.86	5.83	0.79	4.68	82.45	1.73	4.52	14,483
Allegany, Midland	3.10	15.50	74.50	6.90	0.86	4.57	80.71	1.69	5.32	14,070
Allegany, Washington	3.40	15.00	75.10	6.50	1.04	4.63	80.69	1.55	5.60	14,160
Michigan:										
Saginaw, Saginaw	11.91	31.50	49.75	6.84	1.24	5.84	66.56	1.19	18.33	11,781
Missouri:										
Adair, Kirksville	15.98	38.15	37.18	8.69	4.12	5.90	59.09	0.94	21.26	10,798
Caldwell, Hamilton	10.99	35.00	41.37	12.64	4.81	5.43	60.40	1.16	15.56	11,093
Henry, Windsor	13.51	33.24	41.88	11.37	4.08	5.89	59.16	0.85	18.65	10,779
Lafayette, Napoleon	13.44	32.00	40.27	14.29	3.08	5.62	55.83	0.98	20.20	10,232
Macon, Bevier	16.25	33.38	40.97	9.40	3.41	5.75	58.25	1.05	22.14	10,625
Ray, Richmond	13.56	34.29	40.66	11.49	3.77	5.65	58.16	1.04	19.89	10,771
Montana:										
Carbon, Bear Creek	9.67	35.92	46.39	8.02	1.64	5.52	6.166	1.48	21.68	10,832
Cascade, Geyser	8.76	25.72	50.36	15.16	3.91	4.40	58.93	0.79	16.81	10,127
Custer, Miles	29.13	25.33	30.51	15.03	0.55	5.60	40.09	0.54	38.19	6,662
Fergus, Lewistown	15.35	28.27	48.08	8.30	4.53	5.42	61.15	0.71	19.89	10,615
Missoula, Missoula	24.70	29.33	26.11	19.86	0.85	5.56	39.04	0.74	33.95	6,727
Yellowstone, Musselshell	16.66	27.85	48.07	7.42	1.00	5.61	59.22	0.97	25.78	10,226
New Mexico:										
Colfax, Raton	2.12	36.06	50.22	11.60	0.64	4.94	69.96	1.33	11.53	12,965
Lincoln, White Oaks	2.52	34.63	45.99	16.86	0.76	4.97	66.65	1.32	9.44	11,956
M'Kinley, Blackrock	14.69	34.93	41.56	8.82	0.79	5.82	60.93	1.12	22.52	10,809
North Dakota:										
Morton, Leith	36.18	29.77	25.35	8.70	0.68	6.76	39.45	0.59	43.82	6,700
M'Lean, [a]Wilton	35.96	31.92	24.37	7.75	1.15	6.54	41.43	1.21	41.92	7,069
Stark, [a]Lehigh	35.38	29.59	25.68	9.35	1.55	6.61	40.23	0.54	41.72	6,923
Williams, [a]Williston	36.78	28.16	29.97	5.09	0.48	6.93	41.87	0.69	44.94	7,204
Ohio:										
Belmont, [a]Bellaire	4.14	39.30	47.18	9.38	3.96	5.19	69.58	1.20	10.69	12,874
Guernsey, [a]Danford	6.65	33.94	48.86	10.55	3.13	5.30	67.38	1.20	12.44	12,179
Jackson, [a]Wellston	7.71	38.32	42.02	11.95	4.61	5.41	62.49	1.11	14.43	11,515
Jefferson, Amsterdam	3.50	37.98	51.08	7.44	3.09	5.43	73.39	1.46	9.19	13,286
Noble, Belle Valley	5.15	37.34	49.00	8.51	2.94	5.42	70.51	1.50	11.12	12,733
Perry, [a]Dixie	7.55	38.00	46.08	8.37	2.84	5.48	67.02	1.29	15.00	12,128
Oklahoma:										
Coal, Lehigh	7.07	36.41	45.68	10.84	3.64	5.13	64.38	1.44	14.57	11,468
Haskell, McCurtain	2.70	21.07	69.88	6.35	0.77	4.46	81.33	1.67	5.42	14,098
Pittsburgh, Carbon	2.09	27.59	50.25	20.07	5.73	4.46	63.66	1.33	4.75	11,695
Pittsburgh, McAlester	3.58	32.11	59.04	5.27	0.56	5.31	77.11	1.62	10.13	13,615
Oregon:										
Coos, Beaver Hill	16.10	31.10	39.63	13.17	0.81	5.53	51.07	1.19	28.23	9,031
Pennsylvania:										
Allegheny, Bruceton	2.73	36.03	54.98	6.26	1.39	5.26	76.82	1.46	8.81	13,815
Allegheny, Oak Station	3.48	35.15	55.45	5.92	1.18	5.42	75.73	1.45	10.30	13,700
Allegheny, Scott Haven	2.60	32.67	59.41	5.32	0.77	5.39	78.16	1.45	8.91	14,085
Bedford, Hopewell	1.58	16.32	69.98	12.12	1.94	4.09	77.01	1.44	3.40	13,408
Cambria, Barnesboro	2.87	21.44	69.23	6.46	1.52	5.00	80.53	1.19	5.30	14,177
Cambria, Beaverdale	3.44	16.18	73.46	6.92	1.83	4.64	80.61	1.20	4.80	14,114
Cambria, Carrolltown Road	0.93	23.10	69.29	6.68	1.30	4.81	81.64	1.26	4.31	14,485
Cambria, Fallen Timber	3.34	24.06	62.75	9.85	1.80	4.96	76.78	1.25	5.36	13,618
Cambria, Hastings	2.89	23.67	66.34	7.10	1.37	5.02	79.49	1.30	5.72	14,107
Cambria, Johnstown	1.32	14.63	75.24	8.81	1.57	4.26	81.19	1.39	2.78	14,047
Cambria, Nanty Glo	2.84	19.78	70.89	6.49	1.85	4.87	80.83	1.32	4.64	14,285
Cambria, Portage	3.52	17.32	73.27	5.89	1.06	4.78	82.06	1.23	4.98	14,278
Cambria, St. Benedict	2.94	19.52	70.87	6.67	1.76	5.04	79.78	1.26	5.49	14,143

TABLE X.—COMPOSITION AND HEAT VALUE OF UNITED STATES COALS.[1]—(*Continued*)

County, bed or local name	Proximate analysis "as received"				Ultimate analysis "as received"					Heat value, B.t.u. per pound "as received"
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Pennsylvania—*Continued:*										
Cambria, Van Ormer	2.73	24.98	63.64	8.65	0.81	4.89	78.24	1.22	6.19	13,860
Cambria, Vintondale	3.63	18.63	71.20	6.54	1.98	4.90	80.59	1.23	4.76	14,119
Cambria, Windber	3.30	12.50	77.90	6.33	1.04	4.46	81.65	1.27	5.25	14,340
Center, Osceola Mills	2.08	21.46	69.87	6.59	1.99	4.92	80.58	1.29	4.63	14,274
Clarion, Blue Ball Station	1.90	22.00	66.30	9.80	1.95	4.66	78.05	1.14	4.40	13,760
Clearfield, Boardman	2.95	21.29	66.92	8.84	1.35	4.74	78.51	1.19	5.37	13,901
Clearfield, Philipsburg	0.90	21.59	68.49	9.02	1.99	4.57	79.49	1.31	3.62	14,060
Clearfield, Smoke Run	3.73	20.29	68.41	7.57	1.33	4.86	78.92	1.22	6.10	13,970
Fayette, Connellsville	3.24	27.13	62.52	7.11	0.95	5.24	78.00	1.23	7.47	13,919
Indiana, Clymer	2.06	24.46	66.09	7.39	2.19	5.08	79.39	1.19	4.76	14,170
Indiana, Glen Campbell	3.08	27.32	61.16	8.44	1.29	4.99	76.71	1.27	7.30	13,772
Jefferson, Sykesville	2.44	28.44	60.68	8.44	1.32	5.07	76.91	1.31	6.95	13,732
Lackawanna, Dunmore	3.43	6.79	78.25	11.53	0.46	2.52	78.85	0.77	5.87	12,782
Luzerne, Pittston	2.19	5.67	86.24	5.90	0.57	2.70	86.37	0.91	3.55	13,828
Schuylkill, Minersville	2.76	2.48	82.07	12.69	0.54	2.23	79.22	0.68	4.64	12,577
Schuylkill, Tower City	3.33	3.27	84.28	9.12	0.60	3.08	81.35	0.79	5.06	13,351
Somerset, Jerome	1.44	15.21	73.38	9.97	0.90	4.17	79.43	1.34	4.19	13,799
Somerset, MacDonaldton	1.03	16.03	72.57	10.37	2.22	4.29	79.17	1.24	2.71	13,700
Somerset, Windber	2.40	13.50	77.80	6.31	1.26	4.44	82.62	1.31	4.06	14,370
Sullivan, Lopez	3.16	8.59	78.08	10.17	0.67	3.47	79.49	1.10	5.10	13,376
Washington, Marianna	1.44	34.61	57.77	6.18	0.78	5.23	78.76	1.44	7.61	14,242
Westmoreland, Greensburg	2.14	30.02	58.81	9.03	1.17	5.03	76.33	1.56	6.88	13,662
Rhode Island:										
Newport, Portsmouth	22.92	2.78	58.37	15.93	0.10	2.84	58.46	0.18	22.49	8,528
Providence, Cranston	4.54	3.01	78.69	13.76	0.87	0.46	82.39	0.12	1.75	11,624
South Dakota:										
Perkins, Lodgepole	39.16	24.68	27.81	8.35	2.22	6.60	38.02	0.53	44.28	6,307
Tennessee:										
Anderson, Briceville	1.70	35.02	53.14	10.14	1.06	4.97	75.32	1.80	6.71	13,462
Campbell, Lafollette	2.92	32.04	58.23	6.81	1.14	5.19	74.95	1.62	10.29	13,514
Rhea, Dayton	1.76	27.86	49.57	20.81	0.49	4.51	66.24	1.19	6.76	11,666
Texas:										
Houston, Crockett	34.70	32.23	21.87	11.20	0.79	6.93	39.25	0.72	41.11	7,056
Wood, Hoyt	33.71	29.25	29.76	7.28	0.53	6.79	42.52	0.79	42.09	7,348
Utah:										
Carbon, Sunnyside	5.96	38.68	48.77	6.59	1.73	5.43	71.28	1.52	13.45	12,841
Emery, Emery	3.93	40.92	49.22	5.93	0.39	5.52	73.02	1.25	13.89	12,965
Iron, Cedar City	10.35	36.33	43.70	9.62	5.82	5.13	61.24	0.95	17.24	10,874
Summit, Coalville	14.20	36.00	44.80	5.00	1.41	5.79	61.40	1.09	25.31	10,630
Virginia:										
Henrico, Gayton	2.81	25.70	62.47	9.02	1.43	4.90	76.55	1.81	6.29	13,493
Lee, Darbyville	3.42	34.36	58.83	3.39	0.58	5.25	77.98	1.29	11.51	14,134
Russell, Dante	2.76	34.96	56.51	5.77	0.59	5.32	80.13	1.43	6.76	14,148
Tazewell, Pocahontas	3.50	15.50	76.80	4.20	0.73	4.77	83.36	1.08	5.86	14,630
Wise, Georgel	2.48	31.71	60.30	5.51	0.52	5.59	79.69	1.56	7.13	14,252
Washington:										
King, Black Diamond	7.98	37.69	45.95	8.38	0.45	5.60	64.79	1.69	19.09	11,732
King, Cumberland	5.84	31.32	36.46	26.38	0.47	4.80	52.77	1.30	14.28	9,529
Kittitas, Roslyn	3.89	37.00	46.49	12.62	0.37	5.58	68.55	1.31	11.57	12,434
Pierce, Carbonado	3.81	26.60	49.33	20.26	0.39	5.01	63.85	1.93	8.56	11,518
Thurston, Centralia	25.08	32.25	34.02	8.65	0.82	6.37	47.26	.91	35.99	8,170
West Virginia:										
Fayette, Carlisle	4.95	18.16	73.75	3.14	0.82	5.09	82.15	1.48	7.32	14,434
Fayette, Fayette	3.22	22.28	71.68	2.82	0.55	5.11	83.07	1.56	6.89	14,702
Fayette, Hawks Nest	5.00	24.50	67.20	3.30	0.55	5.12	80.06	1.38	9.59	14,280
Fayette, Kay Moor	3.17	25.11	68.81	2.91	0.52	5.09	82.59	1.63	7.26	14,584
Fayette, MacDonald	3.22	17.53	76.46	2.79	0.64	5.01	84.11	1.56	5.89	14,760
Fayette, Page	3.32	28.88	62.72	5.08	0.80	5.29	79.73	1.37	7.73	14,209
Fayette, Sun	2.94	19.69	68.67	8.70	1.86	4.70	77.66	1.45	5.63	13,786
Logan, Holden	1.66	32.89	59.94	5.51	0.93	5.16	78.97	1.26	8.17	14,126
M'Dowell, Ashland	2.80	14.50	77.40	5.33	0.64	4.56	83.39	1.03	5.05	14,550

TABLE X.—COMPOSITION AND HEAT VALUE OF UNITED STATES COALS.[1]—(*Continued*)

County, bed or local name	Proximate analysis "as received"				Ultimate analysis "as received"					Heat value, B.t.u. per pound "as received"
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
West Virginia—*Continued:*										
M'Dowell, Big Four	2.30	16.98	76.21	4.51	0.66	4.36	85.00	1.20	4.27	14,636
M'Dowell, Coalwood	2.19	13.91	75.25	8.65	0.57	4.45	80.69	1.19	4.45	13,995
M'Dowell, Eckman	3.32	16.22	76.35	4.11	0.55	4.67	83.05	1.16	6.46	14,587
M'Dowell, Ennis	3.25	14.46	78.05	4.24	0.48	4.65	84.05	1.12	5.46	14,571
M'Dowell, Powhatan	2.55	13.44	78.57	5.44	0.57	4.58	83.60	1.01	4.80	14,569
M'Dowell, Roderfield	2.32	16.76	69.80	11.12	1.78	4.35	77.46	1.27	4.02	13,514
M'Dowell, Worth	3.00	13.00	78.80	5.23	0.48	4.46	82.84	1.05	5.94	14,500
Marion, Monongah	2.95	35.01	56.44	5.60	0.67	5.33	77.89	1.38	9.13	13,862
Mercer, Coaldale	3.43	14.58	77.89	4.10	0.67	4.79	83.79	1.06	5.59	14,602
Mercer, Wenonah	3.58	13.17	79.10	4.15	0.56	4.90	83.59	1.07	5.73	14,598
Monongalia, Richard	1.63	28.42	62.01	7.94	0.96	5.00	78.24	1.28	6.58	13,937
Preston, Masontown	1.40	26.40	62.92	9.28	1.50	4.83	77.92	1.43	5.04	13,808
Raleigh, Sophia	3.30	14.00	77.60	5.14	0.63	4.60	82.94	1.41	5.28	14,490
Raleigh, Stonewall	3.02	16.06	78.75	2.17	0.80	5.02	85.02	1.40	5.59	15,001
Tucker, Thomas	1.12	20.74	70.38	7.76	1.05	4.52	81.22	1.59	3.86	13,800
Wyoming:										
Bighorn, Cody	17.20	31.33	45.89	5.49	0.35	5.64	59.15	0.85	28.52	10,055
Carbon, Hanna	11.45	42.58	39.33	6.64	0.38	5.27	59.66	0.94	27.11	10,890
Fremont, Hudson	21.27	32.83	42.75	3.15	0.89	6.13	55.91	0.75	33.17	9,779
Hot Springs, Kirby	15.86	33.01	47.39	3.74	0.59	6.06	62.03	1.29	26.29	10,984
Sweetwater, Superior	16.02	33.63	47.60	2.75	0.94	6.11	62.29	1.08	26.83	10,849
Sheridan, Monarch	23.88	34.33	38.44	3.35	0.38	6.29	54.07	1.14	34.77	9,335

portable unit provides a reserve. This system is claimed to require less investment and to be more adaptable to introduction for stations already built. There is, as yet, no general basis for choosing between these systems, but each is installed and works successfully.

The power required for handling, preparing and delivering the coal from coal pile to bunker is from 15 to 23 kw.-hr. per ton. One plant operating with pulverized fuel and with stokers reports labor of 0.213 man-hr. for coal and ash handling per 1,000 kw. of station rating when using pulverized fuel and 0.117 man-hr. for a stoker installation.

The drying of pulverized fuel before or after pulverizing is necessary when the fuel is moist. Both waste-heat driers, steam driers and separately fired driers have been used to dry the coal to a moisture content to not exceed 2 per cent for most satisfactory operation. For pulverizing the coal, mills are used which employ crushers, centrifugal force, balls, rolls and other mechanical agencies to secure pulverization. Most of the mills in operation have a capacity of 6 tons per hour, but larger mills

have been developed and 20 to 30 tons per hour are feasible capacities to build with the present knowledge of the art. The coal is pulverized until at least 60 per cent passes through a 200-mesh sieve.

From the pulverizer mill the coal passes on a screw conveyor, through a helical pump or through a compressed-air conveying system to storage bins near the boilers or directly to the boilers. Several installations are found using each of the systems and their relative merits are still controversial.

FIG. 34.—In the Hudson Avenue station of the Brooklyn Edison Company the coal is distributed to bunkers in cars which can be controlled automatically or by hand as desired.

If the direct feed with compressed air is not used, arrangements must be made to feed the fuel from the bins. To secure uniform and uninterrupted feeding from bins to furnace is difficult because of variation in the moisture content, temperature, fuel demand by furnaces, fineness and aeration. Screw conveyors in combination with high- and low-pressure air are used.

The bins must have sides sloping at least 60 deg. to prevent the coal from collecting and adhering to the walls and a difference of opinion exists as to the relative merits of steel and concrete bins. The bin walls should be kept at a higher temperature than the inside atmosphere to prevent condensation and the coal should

be kept dry and cool if reliable flowage is to be expected. Before the powdered coal is used in the furnace it should be thoroughly separated and mixed and must be supplied through proper burners.

Oil and Gas Handling.—Oil storage by plants burning oil varies from a 3 days' to a 3 months' supply. The oil from tanks or tankers is conveyed by pumps to storage reservoirs, which may be covered earthen or concrete, with oil-resisting lines for heating the oil so it can be handled. No uniformity in

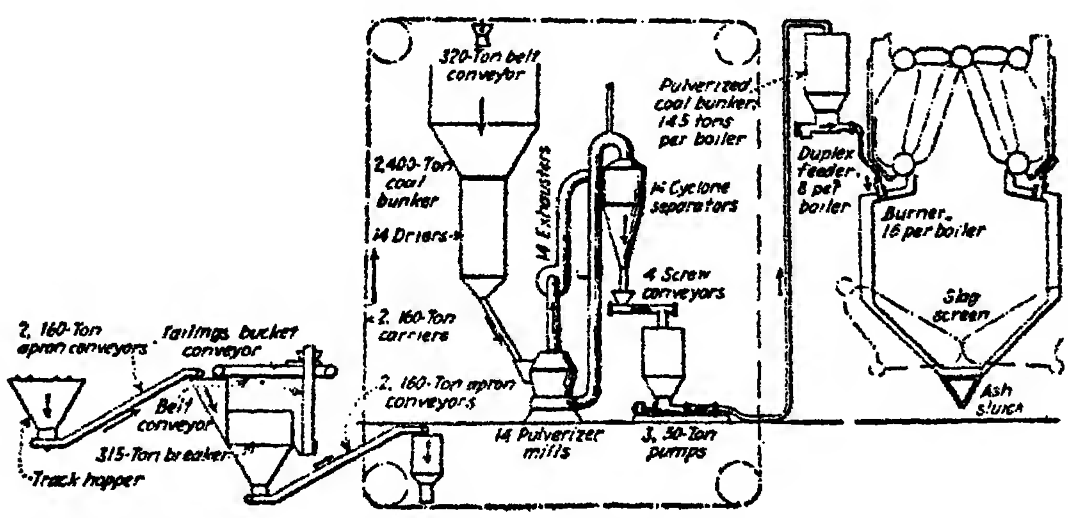

FIG. 35.—Coal preparation system for the Trenton Channel plant of the Detroit Edison Company.

Coal is delivered by rail to the track hoppers of the coal unloading house and elevated to the 315-ton Bradford breaker by 160-ton apron conveyors. It is reduced in the breaker to a fineness of 1¼ in., or less. Large tramp iron and other foreign articles are discharged at the outlet of the breaker and elevated to a picking belt, which again discharges into the breaker inlet hopper, making it possible for the operator to remove foreign material as the opportunity offers. The coal is conveyed from the breaker by two apron conveyors to a 320-ton bucket elevator, which discharges to a belt conveyor over the 2,400-ton coal bunkers.

The pulley at the discharge of this belt is magnetic, and removes small tramp iron before the coal drops to the movable belt which distributes it to the individual bunkers.

The driers are of the stationary steam grid type and are located under the outlet of the coal bunkers. Each drier furnishes coal to one of the fourteen pulverizing mills. The cyclone separators on the mills deliver pulverized coal to either of two pairs of screw conveyors, which discharge into a small hopper above the Fuller-Kinyon coal pumps. The vents from the mills are led into the air ducts at the outlet from the driers. Three 50-ton coal pumps deliver coal to the boiler bins through two 8-in. transportation pipes. The destination of the coal is automatically determined by a system of switching valves in the transportation pipes, the valves being connected to electric switches operated by the flow of coal in the bins. The height of the coal in the bins, and the positions of the switching valves are indicated on a single board near the Fuller-Kinyon pump. The switching valves can also be controlled by means of push buttons located on the signal board.

Alternating-current slip-ring induction motors are used throughout the coal preparation house to drive the equipment, the purpose being to reduce the fire hazard.

practice occurs in the method of transporting, feeding or measuring the oil.

Gas fuel is generally regulated as to pressure and metered in a fire-proof building adjacent to the power station. Various types of regulators are used and some form of orifice meter is used for measuring the large volumes handled. An accurate gas meter of large capacity is yet to be developed.

Ash Handling.—The primary object of a modern central-station system of ash handling is to reduce both labor and

depreciation charges to a minimum. To accomplish this, any method adopted for a given plant will be determined by the way the ashes are delivered from the fire and also by the facilities for final disposition. With the development of large stoker-fired power boilers yielding ashes at a rate of several tons per hour, modern ash-handling equipment has been required to keep pace with the boiler development rate. As a result, four distinct types of ash-handling equipment have appeared, namely, hopper

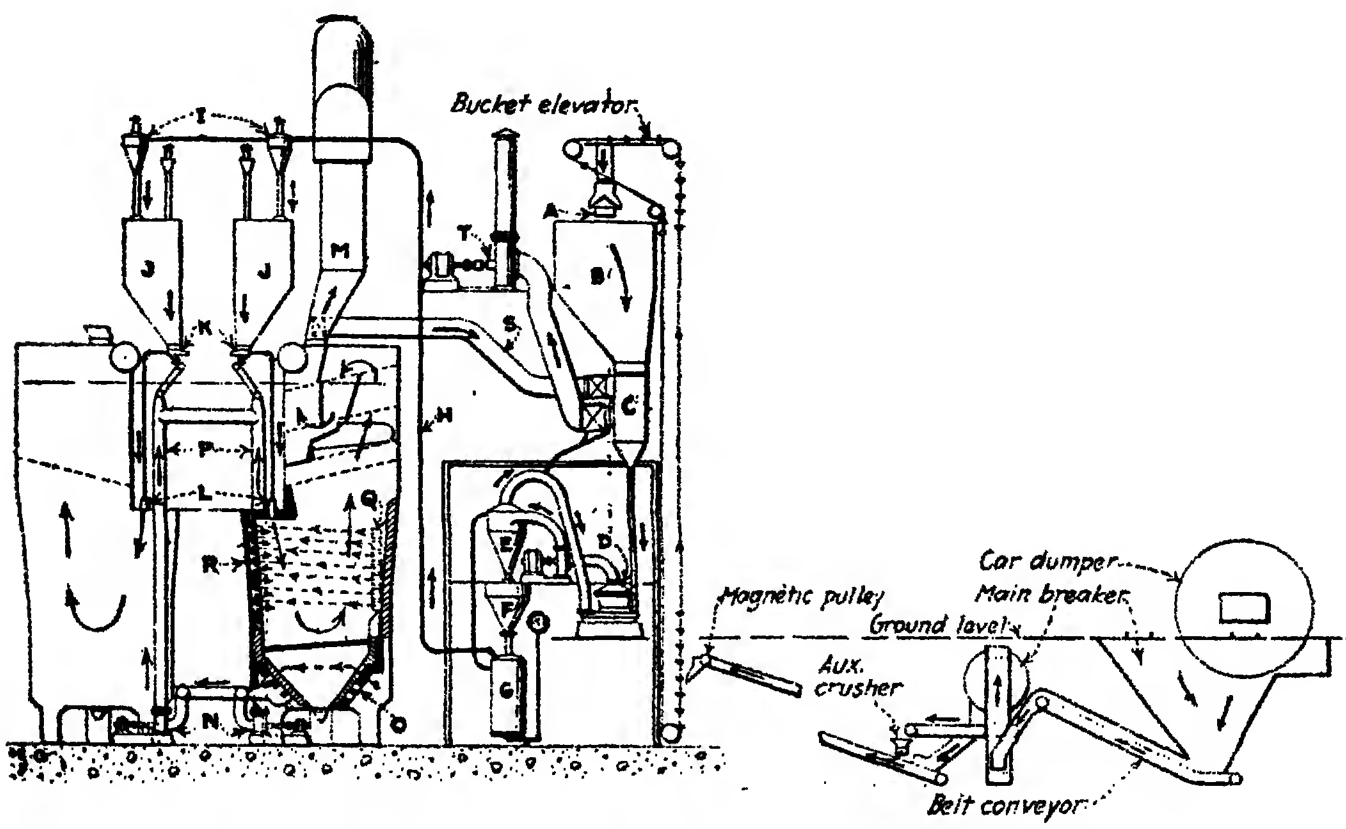

FIG. 36.—Coal preparation system of the Cahokia station of the Union Electric Light and Power Company.

The raw-coal receiving hoppers, crushers and magnetic pulleys are outside the building and below the ground level to permit unrestricted use of the ground. Coal may be received in the rotary-dump hopper or track hopper or can be stored in the open by locomotive cranes which can reclaim the coal and even deliver it to the raw-coal elevator hopper in the remote emergency of failure of the two belt conveyors from the crusher. The raw-coal bunkers and the powdered-coal preparation equipment are in a narrow section of the station proper adjacent to the boiler room but separated therefrom by a fire wall. From the weighing and blowing tanks the powdered coal is delivered to the bins over the boilers by compressed air through 4-in. pipes.

ash pits dumping direct into freight cars, mechanical conveyors, air conveyors and conveyors using water as a means of motion.

From 10 to 20 tons of ash per hour must be handled in larger power stations and this introduces a difficult problem in design and operation. The ash is very hot, around 1800°F., and is hard, abrasive and apt to be in clinker form when coming from stokers or chain grates. It thus creates a great possibility for mechanical wear and tear on handling equipment. In addition to being non-uniform in size, corrosive and offensive acids and gases are formed when the ash, as is usual, is quenched with water. The sulphur

and, to some extent, the phosphorus in the ash combine with water to give a mineral acid which attacks iron and steel.

It has become approved practice to have the ash-handling system independent of the coal-handling system and experience has proved the inadequancy of belt conveyors, bucket conveyors and drag conveyors for handling ash. In their place the two chief systems are the hopper and car and the water sluice, although some steam- and air-conveying systems are used and are being

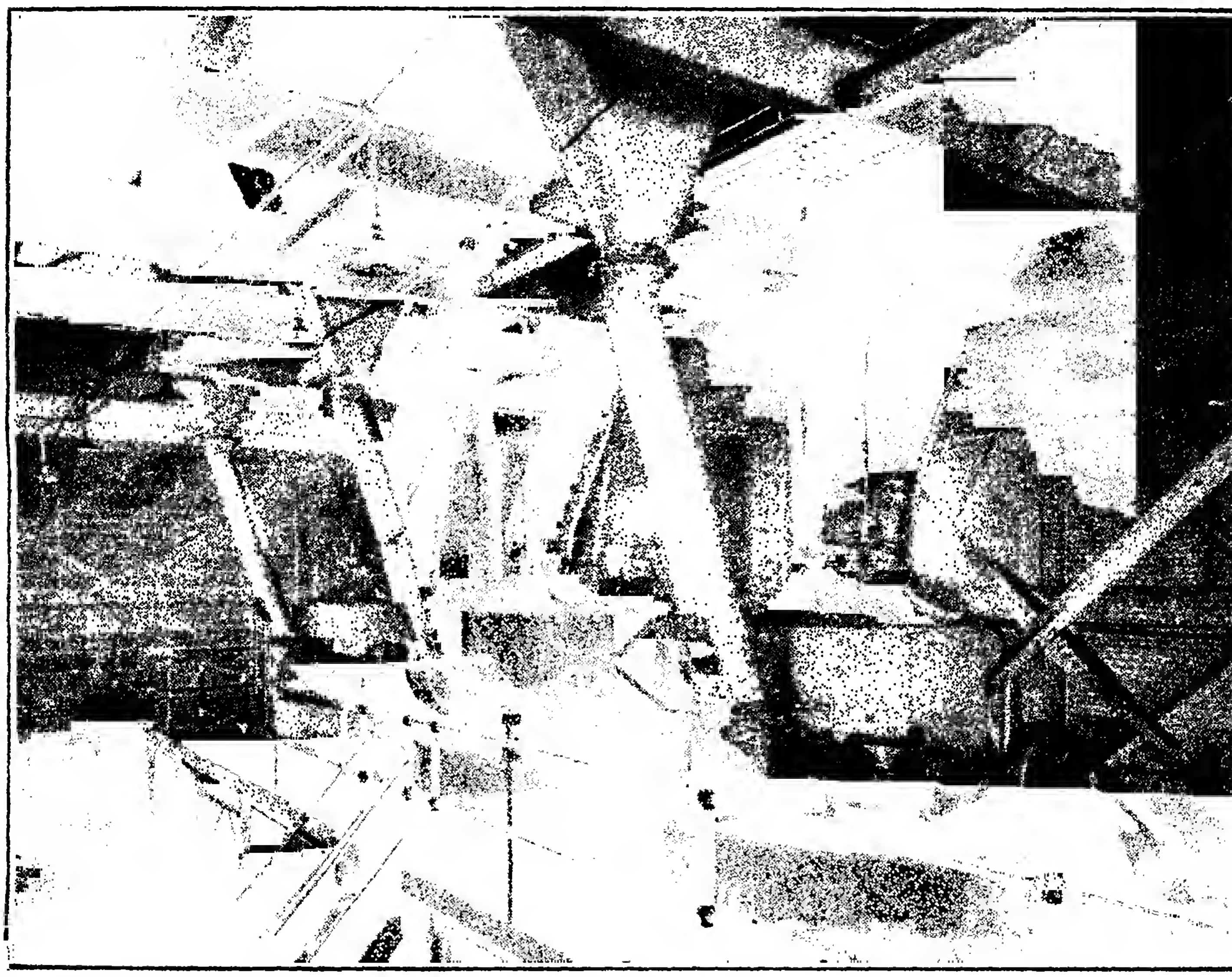

Fig. 37.—View of pulverizing mills in the Valmont station of the Public Service Company of Colorado.

developed. These last, however, are more suitable for handling the ash from pulverized-fuel installations.

The design of hopper ash pits, which are used most extensively in modern plants, depends upon the method of ash removal and the draft system. With underfeed and chain-grate stokers dumping ashes at the rear of the furnace, the top of the hopper will be the width of the fire but of small dimension from front to rear. This arrangement reduces the capacity for storage. In some instances very little capacity may be sufficient, owing to storage facilities outside the ash pit, but 24-hr. capacity should usually be provided for in case of breakdown in the conveyors.

The largest ash-pit capacity is required with conveying systems which are operated intermittently; for example, where ashes are dumped into standard railway cars or into conveyors which might be choked by the direct dumping of an accumulation containing large clinkers and therefore need manual attention.

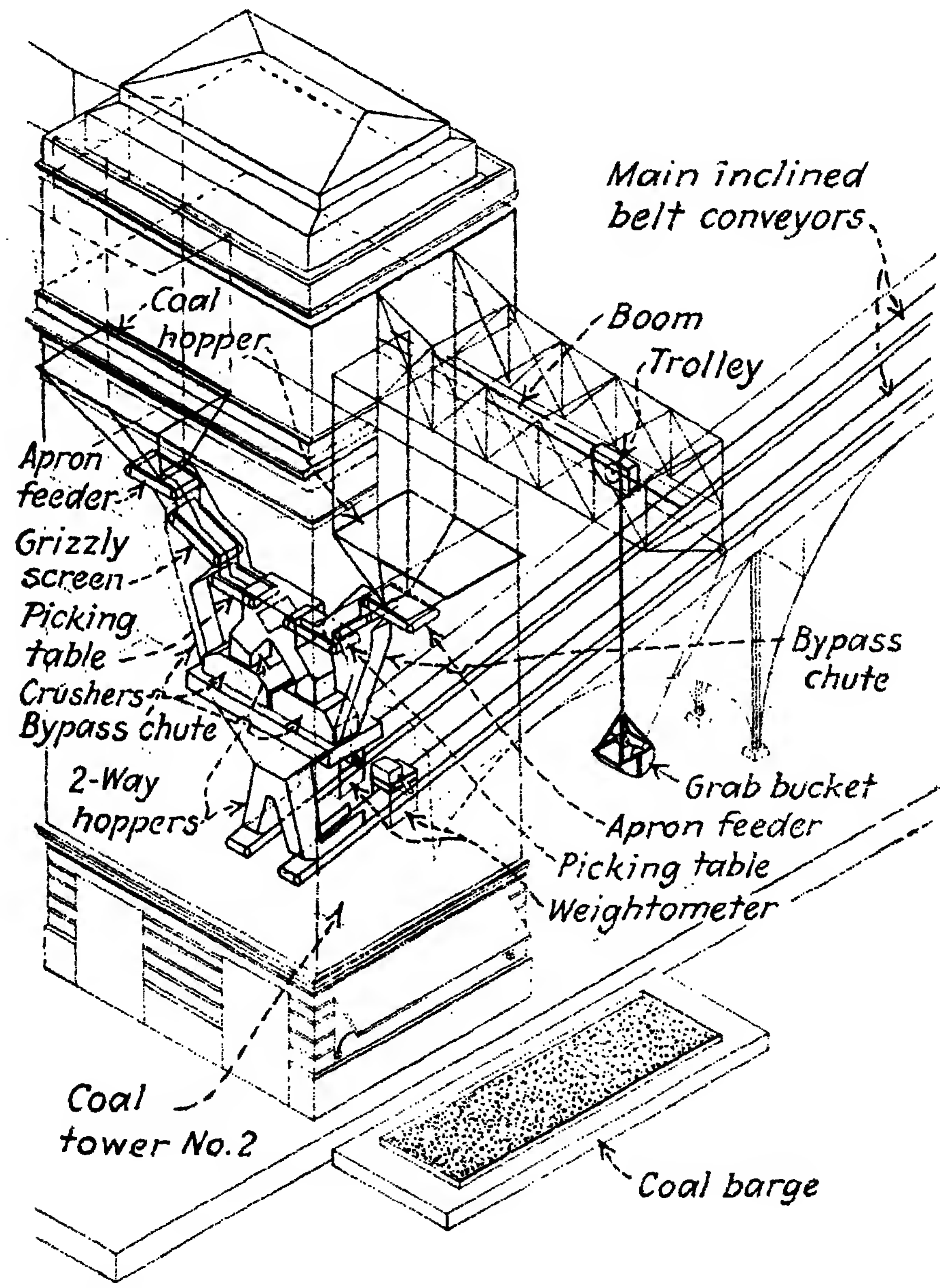

FIG. 38.—Coal tower arrangements for Richmond station of the Philadelphia Electric Company.

In the design of the hopper ash pit the sides should slope not less than 45 deg. in any case, but if one side is vertical, the opposite side may have the minimum slope. If the slope is too small, the ash is likely to arch. The arrangement and use of clinker grinders also influence the design. Where the width of the hopper would necessitate too great a height to get the required

slopes, the ash pit may be divided into a number of discharge openings. Modern practice requires discharge openings of about 30 to 36 in. as a minimum, although their size depends upon the method of firing. When small anthracite is burned with sufficient steam in the combustion air, no clinkers are formed, but modern intensive firing of bituminous coal tends to cause the formation of large clinkers. Therefore the discharge opening should be large enough to pass these without having to break them into smaller pieces or clinker grinders must be installed.

The height of the bottom of the hopper above the basement floor depends upon the system of conveyors adopted. With a locomotive and standard railway cars about 17 to 18 ft. is required: but with a battery locomotive and industrial cars 5 to 6 ft. is sufficient, although a clear head room of 7 ft. is preferable. Many designers prefer to make the hopper sufficiently large to allow the ashes to remain long enough to cool naturally. By allowing some ash to remain when dumping) for the new hot ash to fall upon, the doors and linings are protected.

Although steel shells with reinforced concrete about 6 in. thick have been found satisfactory the most modern construction is to use a structural steel skeleton and a shell of substantial cast-iron flanged plates bolted together. Corrosion is not troublesome because cast iron suffers much less than steel from the acids. If the hot ashes are quenched properly with water sprays, a lining of well-burned hard paving brick proves satisfactory.

Hopper ash pits will usually be provided with doors to retain the ash, to prevent the passage of air and also to allow the ashes to be dumped. With chain grates and with closed-ash-pit forced draft, the doors should be tight to avoid a loss of air pressure and waste of blower power. There are several ways in which dump openings may be sealed. Doors and faces may be machined, flanges may be provided around the edge to maintain a water seal or the frame may be provided with a groove packed with asbestos rope, while the door has a rib or tongue which is squeezed into the asbestos packing by a cross-bar and a screw spanning the door.

The method of conveying ash by emptying ash pits into small dumping cars has a great deal to recommend it since the cars are usually so inexpensive that one or two spare idle cars are not objectionable; also the cars can be repaired without interrupting the ash conveyance. The cars can be moved by men, animals,

tractors or locomotives; they can be run about the premises and dumped to fill depressions, lifted on elevators to dump into an elevated ash bunker or they can be dumped into the bucket of a skip hoist.

The extra cost of foundations and building is less for the hopper-car installation on plants using overfeed stokers or chain grates

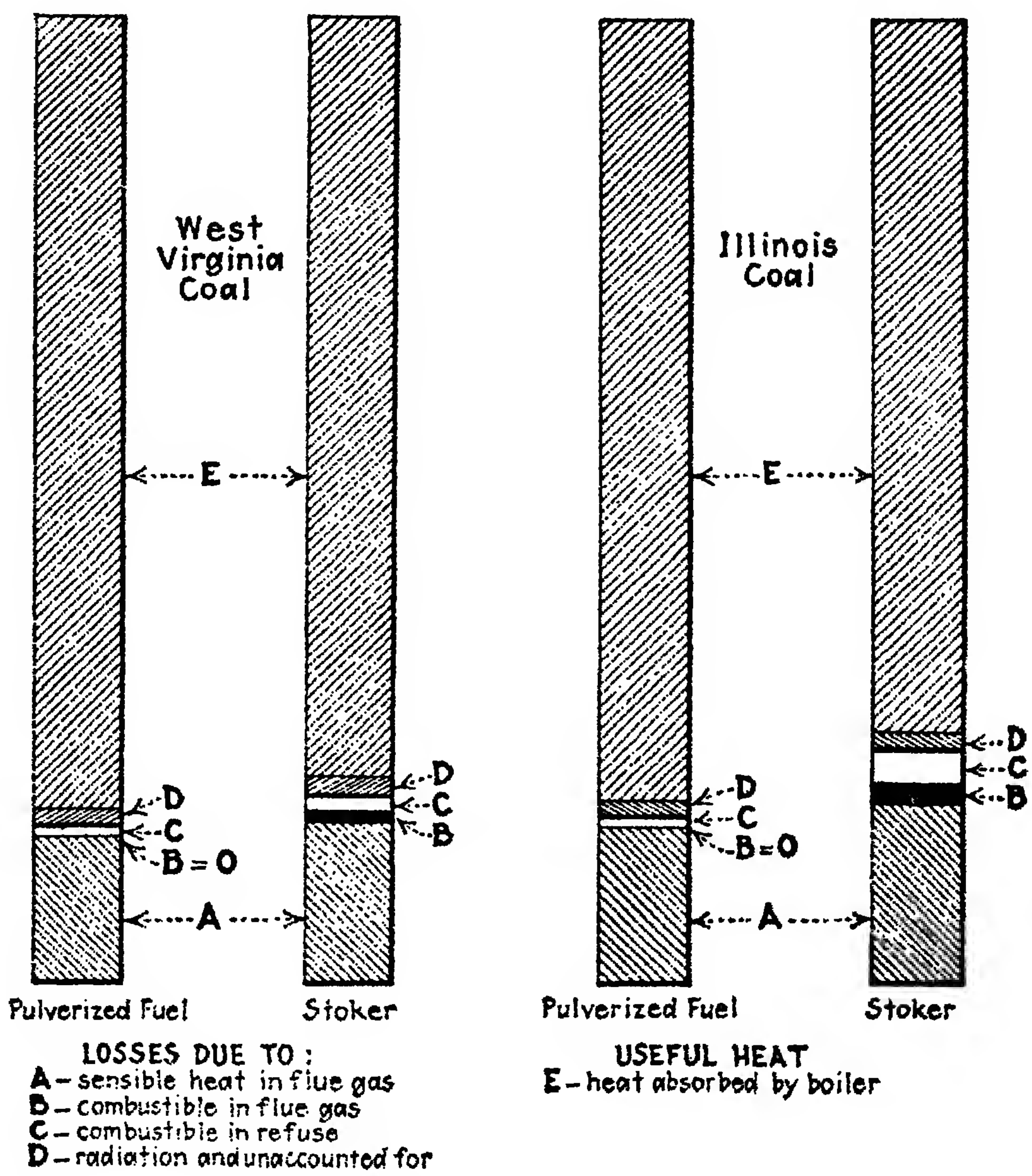

FIG. 39.—Relative performance of stokers and powdered coal in a specific case using two different fuels. (*C. F. Hirshfeld, Electrical World, Sept. 26, 1925.*)

With West Virginia coal, no drying was assumed necessary for pulverized fuel combustion, so the moisture in flue gas was the same with both methods. With Illinois coal it was assumed necessary to dry from an initial moisture of 16 per cent to 6.5 per cent for pulverized-fuel firing. Unless this is taken into account, the results are not comparable for Illinois coal. Coal-drying was done by flue gas, which reduces the exit temperature more than with a stoker installation, thus giving an advantage with pulverized fuel that would not be obtained if the flue gas is subsequently used in economizers or air preheaters. If economizers or preheaters are used, less heat is available to them.

than in those using underfeed stokers because of the space requirements of the firing devices. The relative advantages of railroad car or industrial car for a given installation involves a balancing of all costs and the judgment of the designers as to their relative operating reliability and convenience.

Water-sluice Ash Handling.—This comparatively recent method of handling ash is gaining in favor for large stations. The

ash drops from the hopper to a water trough under the boiler plant. There are several ways of handling the ash—in one the water is stationary and the ash is conveyed along the trough by some form of drag conveyor and discharged into a pit, conveyed up an elevation to cars or conveyed to barges; in another system pure sluicing is used, in which centrifugal pumps drive the water continually along the troughs into a discharge tank from which the water drains through a strainer and is used again or is wasted and the ash is then handled by grab bucket to cars or barges; in still another method the ash is sluiced intermittently after falling into the stationary water in the trough. These methods have

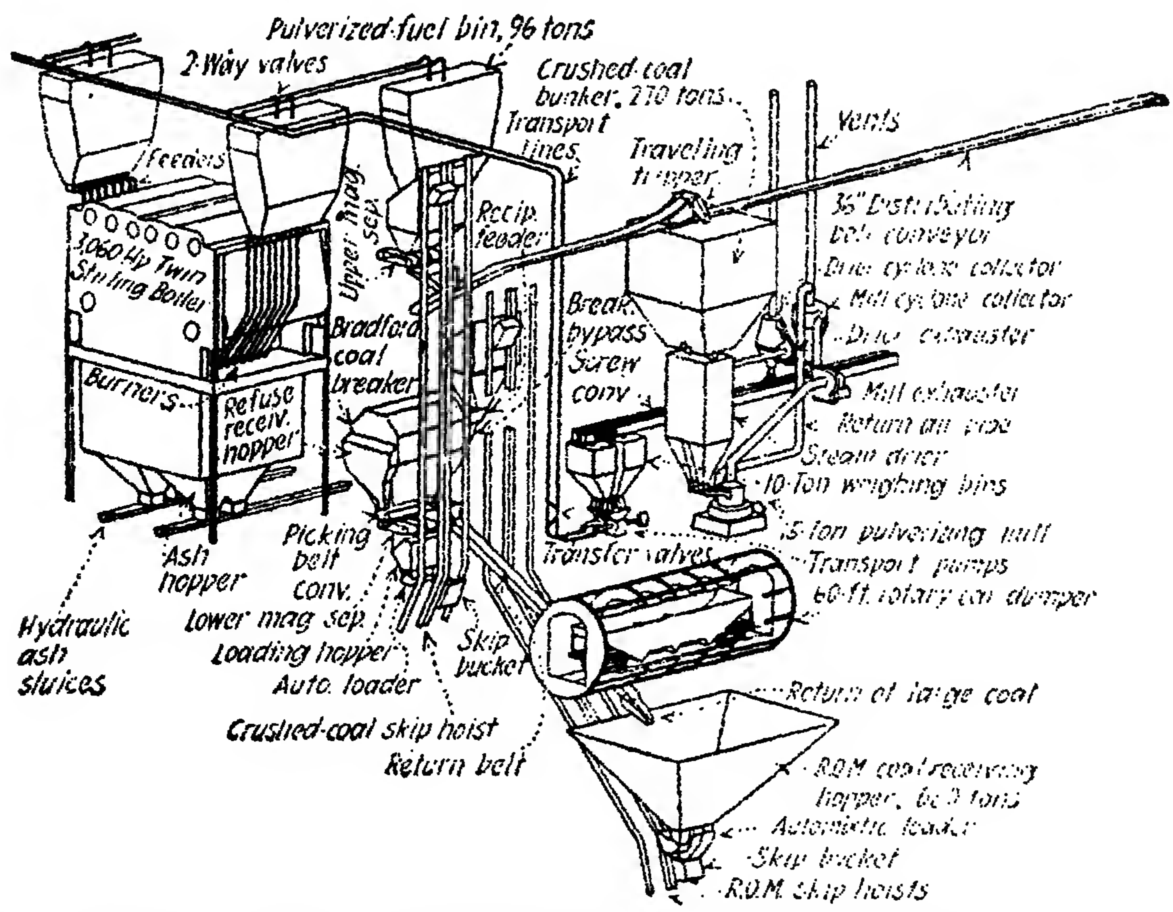

FIG. 40.—Isometric view of coal-handling and preparation equipment in Avon station of the Cleveland Electric Illuminating Company.

the advantages that the building may be low and all dust and gases are eliminated, but have disadvantages in that the ash is abrasive and will wear the troughs or conveyors, that air leakage is difficult to eliminate from the combustion chamber and that the troughs must have a grade which becomes troublesome if the plant is large—sometimes a 10-ft. difference in level is required between the ends of the trough, and in this event foundation costs become high. However, only about ¾ hp. per ton of ash is required in sluicing and care in laying out an installation will eliminate leakage and the bad effects of grades and abrasive actions. Figure 26 shows a modern chain-grate installation with ash handling by hopper and car. Figure 27 shows a cross-section

of the Hell Gate station of the United Electric Light and Power Company which uses the continuous sluicing method of handling ash in a concrete trough having a special lining of vitrified tiles.

Air Conveyors.—With the air-conveyor ash-handling system there are two methods of generating the air current. In one the pipe outlet is connected to the ash-storage tank, in which a vacuum is caused by means of a steam jet, and in the other the air current is induced by a steam jet between the ash intake and the outlet. It is customary to locote the motor jet at an elbow, as it is then convenient to aim the jet in the new direction. Ash openings may be arranged in any position desired, such as in the firing floor in front of hand-cleaned ash pits, near the bottom of hopper ash pits or connected to pipes to draw soot and fly ash from the later boiler passes. They can serve several lines of boilers as easily as one. The maximum capacity of a 6-in. conveyor is about 4 tons of ash per hour, that of the 8-in. conveyor 6 to 9 tons and that of the 9-in. conveyor from 10 to 15 tons per hour. This capacity depends largely upon the size of the pieces of ash.

The steam consumption of air conveyors depends upon the length of the conveyor, the height to which the ash is lifted, the number of bends and the care used to economize steam during operation. With coal containing 12 per cent ash 2 tons of steam would be used for 100 tons of coal. Taking an average evaporation of 9 lb. water per pound of coal, the conveyor will use 2 tons of steam out of every 800 tons generated, or approximately 0.2 per cent. To allow for careless operation it is advisable to allow 0.3 to 0.4 per cent in arranging for extra distillation for make-up water. If the make-up water for the station is 2 per cent, then the distilling capacity should be increased by 20 per cent.

To prevent waste of steam in air-conveyor systems there is on the market an electrically controlled steam valve which consists of a foot-operated switch placed in a convenient position near each ash intake so that steam is blowing only when the attendant is actually at work at any particular intake. The air system is very good for pulverized-fuel installations.

A study of existing stations shows that either the dumping of ash into cars or water sluicing is practiced by the majority of stations, but local conditions or the use of pulverized fuel may warrant a departure from this practice.

CHAPTER V

STEAM GENERATION AND UTILIZATION

The production of electrical energy in fuel-burning stations is a very rapidly changing art with respect to equipment and methods used and the ultimate standards are difficult to predict. Each year sees marked changes and improvements in equipment and methods, brought about by increasing economic pressure for more efficient production and by pressure resulting from the enormous increases in power demands.

Any fuel-burning station has two major problems to solve in securing efficiency: one to transfer all the heat from the fuel to the steam, and the other to transform all the energy in the steam into electrical energy. These ideals cannot be attained but major improvements in furnaces, boilers and condensers, together with new methods of operation, secure some great savings each year. At present, a tendency is noticed toward the use of high pressures and temperatures in the steam and an extreme application of the recirculation principle. The stack gases and the circulating water in the condensers are the chief sources of loss and equipment and operating methods are being developed and changed in an attempt to reduce these losses by so circulating and absorbing the heat in the water and gas that the exhausts have a minimum heat content. Needless to say, economics is the balance wheel in carrying out such designs, but in addition there are practical difficulties in operation, design and equipment applications which limit the commercial use of the thermodynamic principles very materially.

Trends in Practice.—As practiced today, about 550-lb. steam pressure, 730° steam temperature and 28.7-in. vacuum are conservative upper limits for steam conditions in stations, yet semi-experimental plants are being constructed that exceed these limits. In these stations there are differences in the installations and methods used in an attempt to secure greater economy. One type utilizes steam pressures of 1,200 lb. at a temperature of 750° in the boiler. This steam operates a turbine at the same pressure

and then is exhausted, while still dry, at a pressure of about 400 lb. into a separately fired or live steam reheater where the temperature is raised until superheat exists. The steam then operates another turbine cylinder and exhausts to the condenser, or, in some designs, two cylinders may be used in the last part of the cycle, one operating between 400 lb. and zero pressure and the exhaust steam from this after reheating operates another cylinder under vacuum conditions. This type of operation utilizes the regenerative cycle and a large part of the theoretical gain in efficiency is obtained indirectly through the use of the reheating operation.

Another type of station has been suggested which will utilize the same initial pressure and temperature and the high- and low-pressure turbine cylinders but not the principle of reheating. The moisture in the steam after exhaust from the high-pressure turbine is to be removed by mechanical means and the steam then used in the low-pressure cylinder.

In the majority of large stations recently erected it is customary to use electric drive for major auxiliaries and to practice multi-stage bleeding of the main turbine units for heating the feed water. If the steam is bled from the proper turbine stages, pressures and temperatures can be adjusted so that the feed water can be heated in successive stages to a degree almost equal to that of the boiler water temperature and a very efficient thermal system exists. The practical disadvantages of the bleeding system, however, as yet limit its application to two-, three-, and four-stage bleeding. Another trend is toward the use of the mercury boiler type of station such as has been installed at Hartford, Connecticut. In this installation of the Hartford Electric Light Company a low-pressure mercury boiler is used in combination with the main plant. The boiler operates a mercury vapor turbine and the exhaust mercury vapor is used to generate steam from water and the steam is used in main unit turbines. The experimental installation of about 3,000 kw. has been so promising that a larger unit is to be built.

Developments in Practice.—The early steam-turbine unit had a thermal efficiency of about 14 per cent as measured by the B.t.us. in the energy at the bus bars divided by the B.t.us. in the steam supplied the turbine less the B.t.us. returned to the boilers in the condensate. This early efficiency has been increased greatly by improvements in the design of all equipment in the stations, by

the use of higher pressures and temperatures and by improved practices. In Table XI the change in turbine-alternator conditions with the years and the anticipated conditions in the near future are indicated in a general way.

TABLE XI.—CHANGES IN POWER STATION PRACTICE AND IMPROVEMENTS IN THERMAL EFFICIENCY

Year	Approximate size of units, kilowatts	Gage pressure, pounds per square inch	Steam temperature at throttle, degrees Fahrenheit	B.t.us. per kilowatt-hours	Thermal efficiency	Bleeding and reheating
1903	5,000	175	375	23,500	14.5	
1915	20,000	200	560	14,500	23.5	
1922	30,000	230	625	13,400	25.5	
1923	30,000- 45,000	250	650	12,500	27.2	
1924	30,000- 50,000	375	700	11,200	30.5	Bleeding only
1924	35,000- 60,000	550	725	10,300	33.1	Bleeding and reheating
1925	60,000-150,000	550	725	10,000	33.8	Bleeding and reheating
1925	60,000-200,000	1,200	725	9,000	38.0	Bleeding and two reheatings

If the thermal efficiency of stations is computed by taking account of all losses, or is the B.t.us. in the energy at the bus bar divided by the B.t.us. in the coal used, a general development in the art may be noted by the approximate figures of Table XII.

TABLE XII.—IMPROVEMENT IN EFFICIENCY OF GENERATING PLANTS

Year	Size of units, kilowatts	Gage pressure, pounds per square inch	Steam temperature at throttle, degrees Fahrenheit	B.t.us. per kilowatt-hour	Equivalent pounds of coal per kilowatt-hour	Thermal efficiency of station
1903	5,000	175	375	37,000	2.64	9.2
1915	20,000	200	590	22,000	1.56	15.6
1923	35,000	230	625	20,000	1.43	17.1
1924	50,000	375	700	15,800	1.13	21.7
1926	50,000-160,000	550	725	14,500	1.04	23.6
1926	100,000-200,000	550	725	14,200	1.01	24.1
1926	100,000-200,000	1,200	725	12,800	0.91	26.6

The stations listed in Table XII for 1926 are proposed stations with efficiencies based on design analysis. One or two existing stations have already reached or bettered these efficiencies under high load factor conditions. These stations operate with stage

bleeding and steam reheating. Thus it is feasible and economical to install stations which have no difficulty in attaining a performance of 14,000 B.t.u. per kilowatt-hour under favorable load factor conditions.

Perhaps a better way to measure progress is on the basis of improvement in system performance. On a large metropolitan system with several plants both old and new and having a comparatively low load factor, the B.t.us. have decreased from a value of 30,000 per kilowatt-hour in 1920 to 22,000 per kilowatt-hour in 1926.

Pressure and Temperature.—The higher the initial temperature of steam the better the efficiency of its utilization in the working cycle of the turbine both because of a greater amount of available heat in the steam and an increased thermodynamic efficiency of utilization in turbines. The limitations to the application of this principle are fixed by the strength of materials used, the amount of condensation and the cost of the installation. About 800° seems to be the upper commercial operating limit, but the critical temperature of water is 704° at a pressure of 3,200 lb. and these are upper theoretical limits. One small boiler utilizes these values to produce steam without the loss due to latent heat, and developments are continuing.

Boiler materials ordinarily used decrease in tensile strength and ductility very rapidly when the temperature exceeds 900°.[1] So, with a water temperature of about 615° at a pressure of about 1,500 lb., the fire side of the boiler material is limited to a temperature of about 800°. Also pipe steels decrease in tensile strength rapidly at temperatures over 700°, but the material in contact with the steam is at a lower temperature than the steam and the thickness can be increased if necessary—the joints are the chief source of trouble. The temperature of the inner surfaces of superheaters, however, is higher than the steam temperature at their outer surfaces, which is around 1500°, depending on their location in the boiler, and only by using some material as a covering to absorb the heat can they be used at higher temperatures. Their location in the furnace is flexible, however, so that proper temperatures can be obtained.

[1] MILLANBY, A. L., and KERR, W.: "The Limiting Possibilities of Steam Plants," read before North East Institution of Engineers and Shipbuilders, England. Feb. 27, 1925

Since valves and fittings are made from cast materials, they find most difficulty in operating under high temperature conditions. The proportioning of the valve surface is very important in order to distribute temperature stresses uniformly and yet globe valves of special design can be obtained for operation at a temperature of 900°. Gate valves have an upper temperature limit of about 700°.

The turbines have an upper commercial limit of about 1,500 lb. at 750°F. The high temperature is particularly troublesome because of its resultant effect on the expansion and contraction of the pipe, valves, joints and turbine wheels.

Much experimental work is now going on to determine many data needed to fix the strength of materials under high-temperature conditions and to secure steam table data which can be used with confidence in the upper ranges.

Cost Variations.—About 25 per cent of the total station cost varies in price with pressure and temperature, i.e., boilers, piping systems, turbines and auxiliaries; and experience indicates that, considered as a whole, the high-pressure station is not much more expensive than the low-pressure station,[1] for although a 400-lb. boiler and turbine may cost about 50 per cent more than a 300-lb. boiler and turbine, there are incidental savings in space, volume, piping and other items which compensate for these increases.

As the cost of coal increases and the load factor increases the advantages of higher pressures become greater in economic value. Increasing the degree of superheat results in a large return on the investment, provided the materials will withstand the temperature. For any given station design an analysis should be made which weighs capital charges against operating savings in terms of the pressures, temperatures and installations that might be used in the station.

The stations that have used reheating have had considerably increased capital charges and operating complexity to offset the thermal gains. This practice is still on trial, so to speak, but new methods and new equipments are being developed which seem to offer good possibilities for capitalizing on the thermal gains made possible by reheating. Reheating increases the theoretical efficiency only slightly but should offer indirect savings

[1] DeForest, C. W., "Increased Economy Warrants Increased Investment," *Electrical World*, Sept. 26, 1925.

through a reduction of friction losses with low-pressure stages of the turbine.

In a recent paper,[1] C. F. Hirshfeld and F. O. Ellenwood estimated that increasing the steam pressure from 200 to 1,200 lb. per square inch will increase the cost of all equipment affected by the steam about 30 per cent for any particular cycle. The curves of Fig. 41 show the variation in total station cost as estimated by the same authorities, as deduced, to be 14 per cent

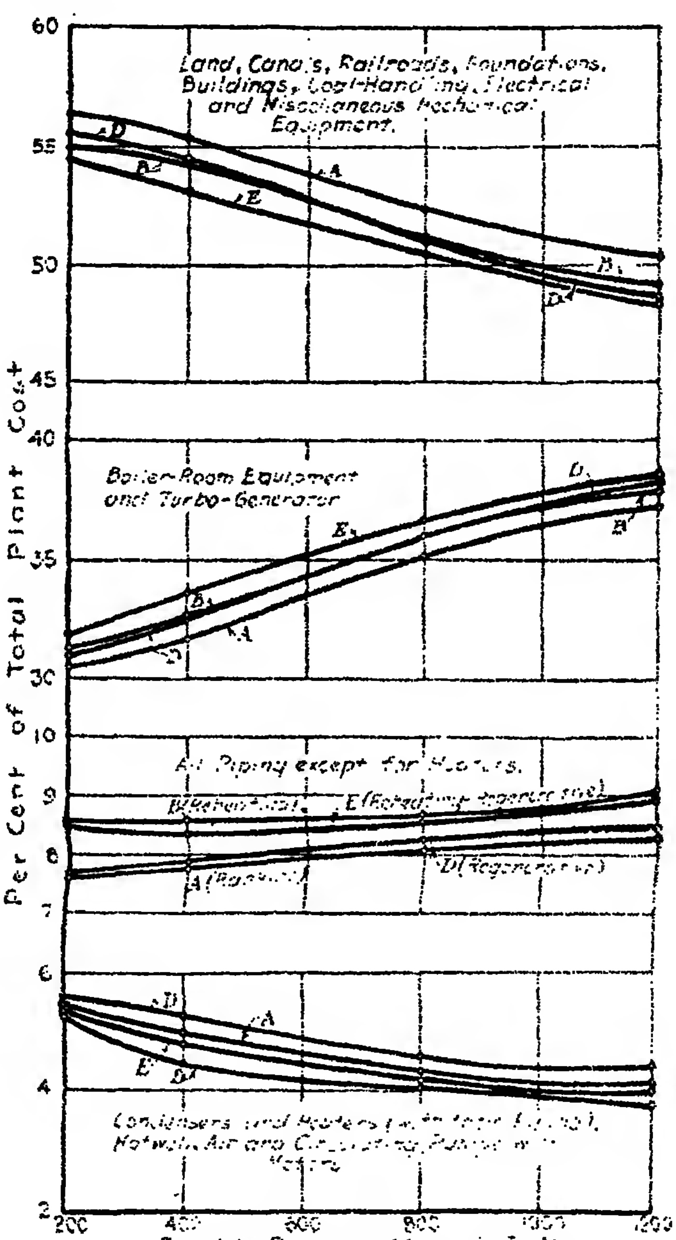

FIG. 41.—Analysis of plant investments when using various pressures and steam cycles. (C. F. Hirshfeld and F. O. Ellenwood, A.S.M.E., 1923.)

greater than for the 200-lb. station. Figure 42 shows estimates of coal consumption when using the various cycles at the range of pressures considered in the same paper. Figure 49 shows an analysis by C. W. De Forest to determine capital expenditure justified by increased thermal efficiency.

Pressures.—Since the practical upper limit of temperature on account of materials is about 800°, the designer has to decide on

[1] "High Pressure, Reheating and Regenerating for Steam Power Plants," A.S.M.E., 1923.

the proper steam pressure to use, and this involves a rather elaborate study of thermo-dynamics and costs. The theoretical thermal gain must be determined and this must then be modified by application to existing apparatus. The effect of pressures on operation and future changes and the balancing of the economic equations must also be made. A typical analysis on a theoretical basis is given in Fig. 43 as made by I. E. Moultrop and Joseph

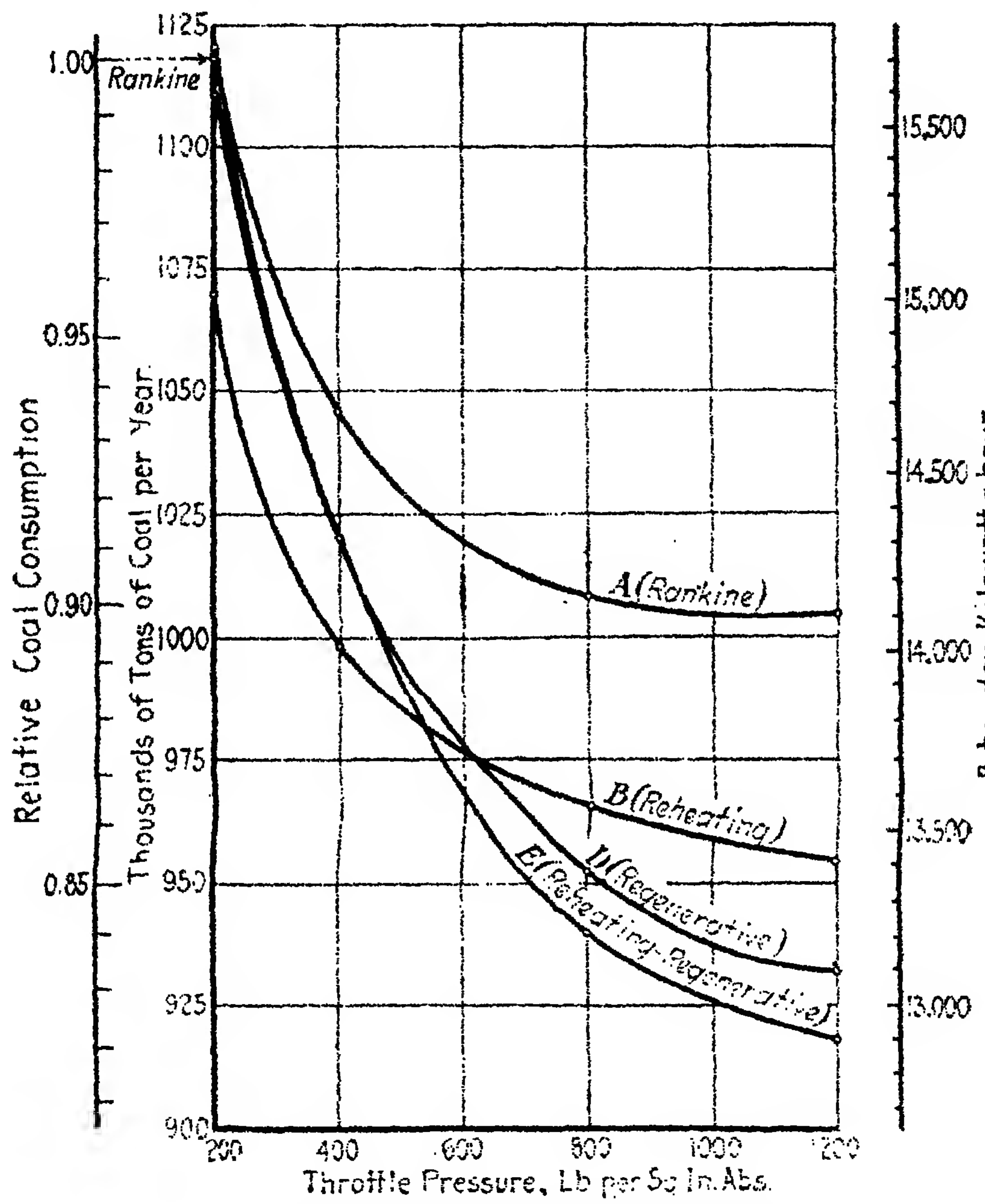

Fig. 42.—Estimates of coal consumption for stations using various steam cycles at various pressures. (*C. F. Hirshfeld and F. O. Ellenwood, A.S.M.E.*, 1923.)

Pope for the Edgar Station of the Edison Electric Illuminating Company of Boston.[1] Although 600 lb. was the theoretical best pressure, cost conditions brought about a decision to use 375 lb.

Economic Determinations.—A good method of analysis for deciding upon the proper steam pressure to use is given by L. C. Kemp in the *Electrician*, of London, June 30, 1922. This analysis is based on an equation for the overall thermal efficiency of a station:

[1] A.I.E.E., 1923.

Efficiency = Average boiler efficiency a.
$\times$ station coefficient b, covering radiation, leakages, steam for auxiliaries and blow downs.
$\times$ station coefficient y, representing the ratio of units sent out to total units generated.

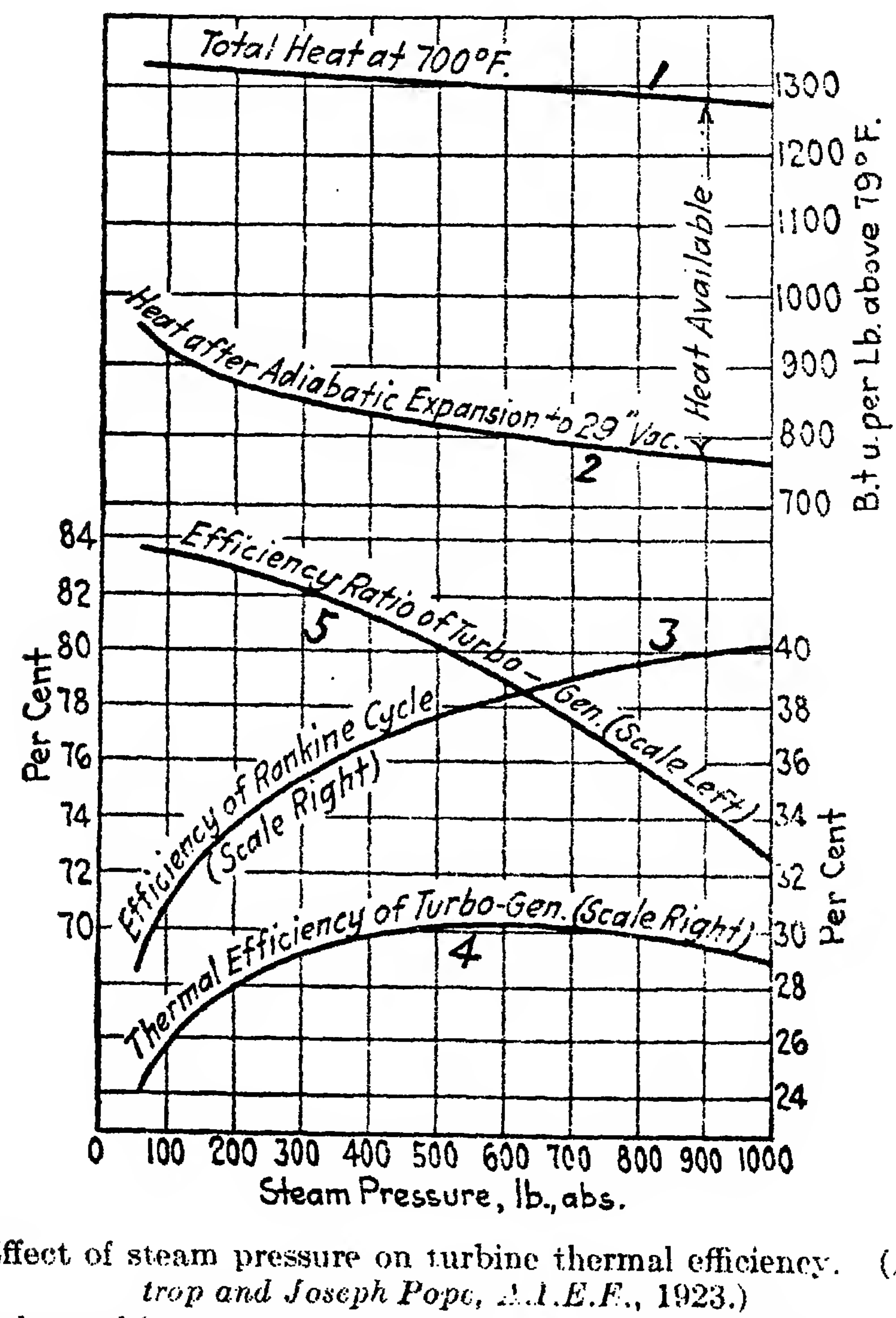

FIG. 43.—Effect of steam pressure on turbine thermal efficiency. (*I. E. Moultrop and Joseph Pope, A.I.E.E.*, 1923.)

Curve 1 is the total heat in 1 lb. of steam at 700°F. above 79°F. Curve 2 is the heat remaining in the steam after perfect adiabatic expansion to 1 in. absolute. The vertical distance between Curves 1 and 2, therefore, is the B.t.u. per pound of steam theoretically available for work. Curve 3 is the available heat as a percentage of the total initial heat of curve 1 and represents the efficiency of the Rankin cycle at varying pressures. Curve 4 is the best efficiency to be expected of turbo-generators in converting available heat into electrical energy. Curve 5 is the product of curves 3 and 4 and shows the percentage of total heat actually converted into electrical energy or returned to the boiler in the condensate.

$\times$ heat conversion coefficient d (or Rankine efficiency).
$\times$ average turbine thermo-dynamic efficiency u.
$\times$ average alternator efficiency n.
$= a, b, y, d, u, n.$

The coefficients a, u and n will be average values depending on the load curve and plant operating conditions. The value of d will be in the order of 30 to 40 per cent and those of the other coefficients 80 to 98 per cent, so that a slight gain in the efficiency of the conversion coefficient has a relatively greater effect on overall efficiency than any of the other coefficients. Figure 44 shows the influence of pressure on the heat-conversion coefficient and is taken from data of Mr. Kemp. It shows that the economy rate of increase lessens as the pressure increases, but these curves

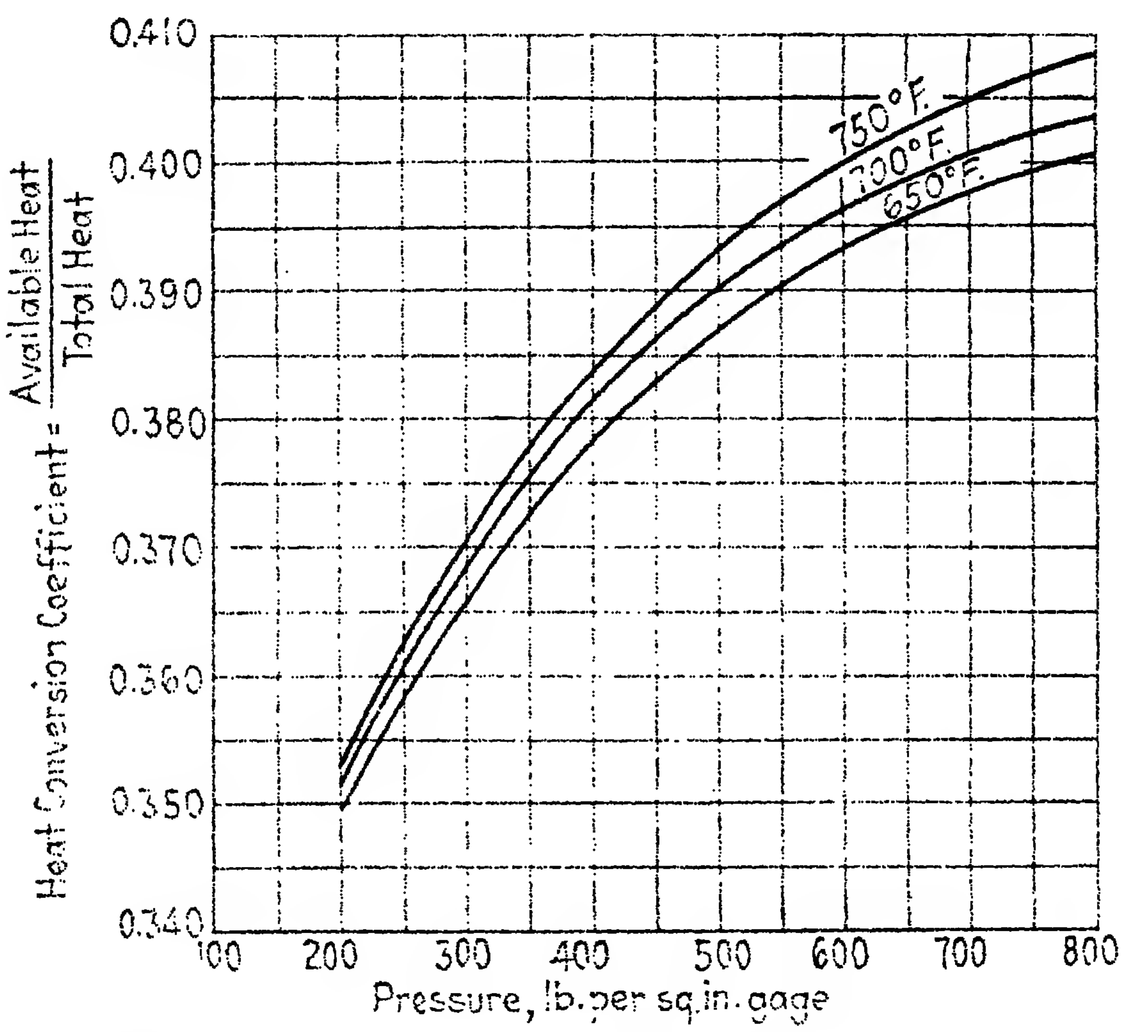

FIG. 44.—Variation of heat-conversion coefficient with pressure. (*L. C. Kemp, Electrician, June 30, 1922.*)

do not consider the effect of using a regenerative cycle. The data are based on 28.7-in. vacuum, 10,000-kva. turbines and total heat from 150°F. Figure 45 shows the combined heat-conversion and turbine thermo-dynamic coefficients as plotted from data in Mr. Kemp's article. Mr. Kemp computes the effect of increases in capital cost and works out a specific example, as indicated by the curves of Fig. 46.

Such analyses are valuable as preliminary attempts to attain an economical selection of steam conditions in the station. After these have been determined within certain limits and the chief items of equipment are selected, a heat analysis of the

station on a B.t.u. basis should be made to determine the expected economies of the assembly. Starting with the fuel, the heat stream should be studied, including that delivered to the steam, to stacks, to circulating water, to economizers if used, to superheaters and to turbines. In addition all radiation losses, leakage losses and internal energy consumptions should be com-

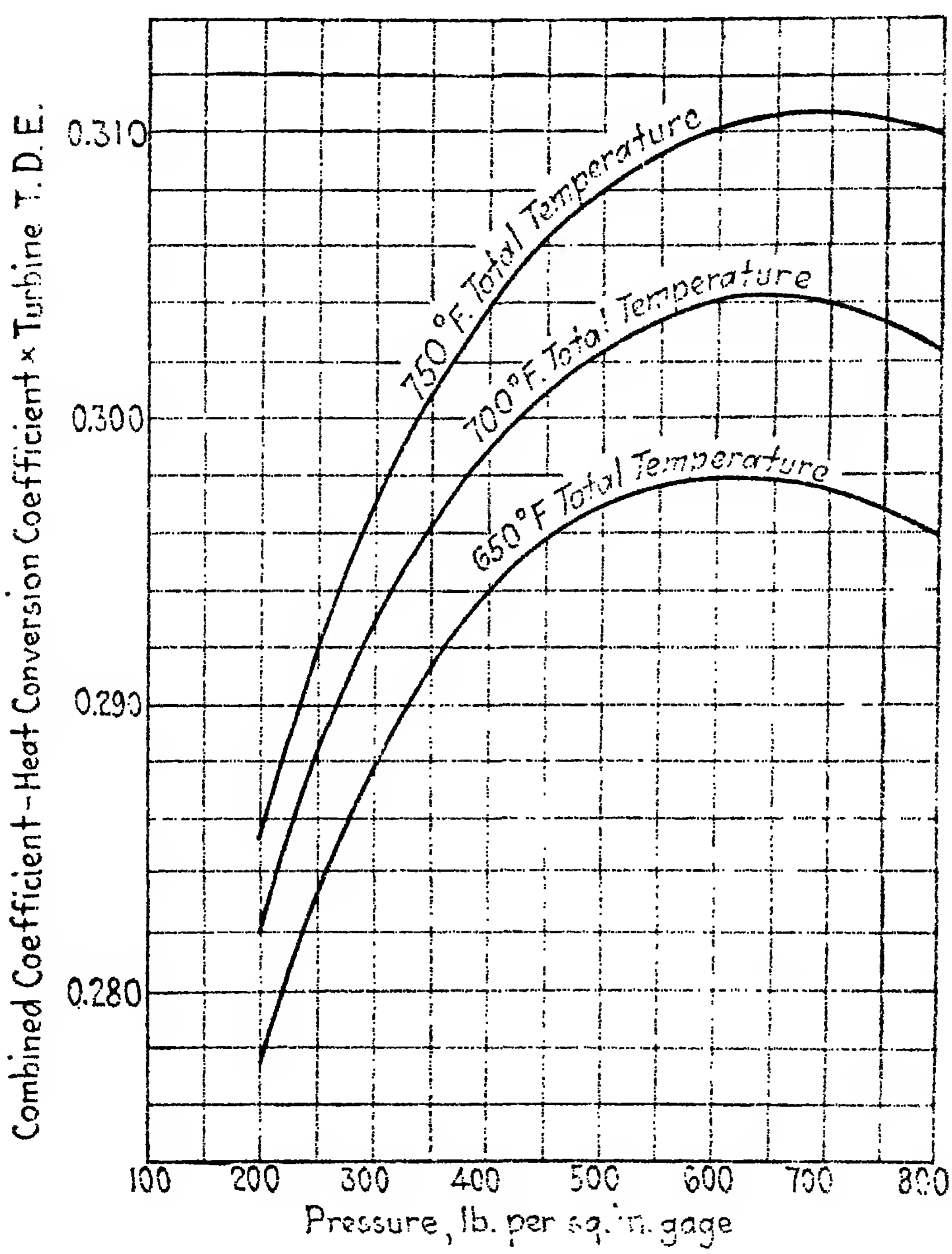

FIG. 45.—Variation of combined coefficient with pressure. (*L. C. Kemp, Electrician, June 30, 1922.*)

puted, including the effect of unburned fuel, banking, blow downs, drips, etc. The heat returned by heat-saving equipment should be credited. In this way a B.t.u. analysis or heat balance will prove very valuable when combined with cost elements to determine the relative advantages of different systems or types of equipment. The use of a station Willans line is very helpful in making the analysis. Figure 47 shows a heat-stream diagram for

very efficient operating conditions as developed by Prof. W. J. Wohlenberg.

Tests and Heat-balance Computations.—The Power Test Code Committee of the A.S.M.E. has presented a tentative draft of a test code for stationary coal-fired boilers. Similar codes are available for boilers using liquid and gaseous fuels.

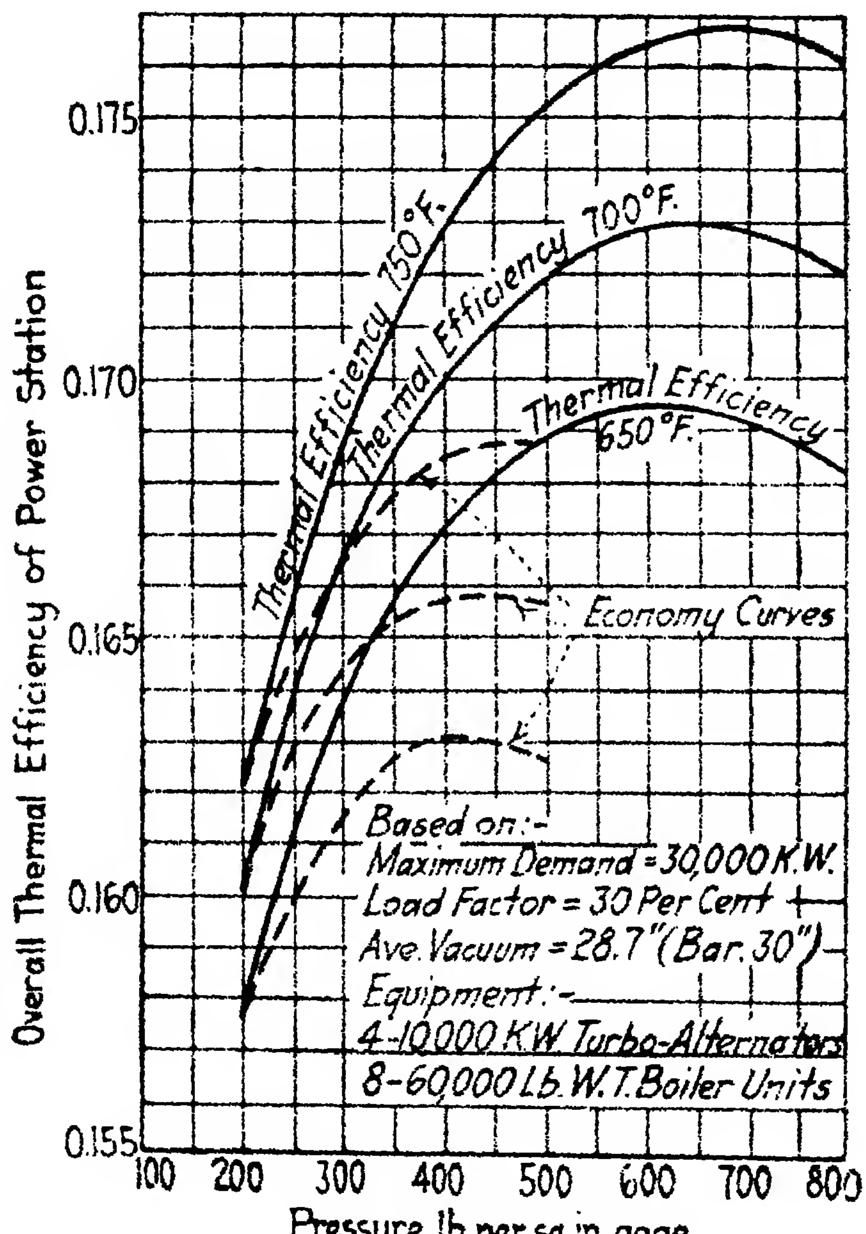

FIG. 46.—Variation in thermal efficiency and economy with pressure. (*L. C. Kemp, Electrician, June 30, 1922.*)

Theoretical Possibilities of Steam Cycles.—Until recently, steam turbines have operated on the Rankine steam cycle. In this cycle the steam is superheated and generated at a constant pressure in the boiler and is then expanded adiabatically in the turbine, after which it goes to the condenser. On the basis of 700° steam temperature, Table XIII gives the theoretical efficiencies at various steam pressures at the throttle for a back pressure of 1 in. of mercury at the exhaust.

TABLE XIII.—THEORETICAL EFFICIENCIES OF THE RANKINE CYCLE

Throttle Pressures, Pounds per Square Inch	Theoretical Efficiency
300	35.5
400	36.6
500	37.5
600	38.2
700	38.8
800	39.2
1,000	40.1
1,200	40.6

From the data it is noticed that the theoretical efficiency increases slowly at the upper pressure limits and as a practical cycle the amount of moisture in the steam during the expansion would greatly lower the benefits derived from using the higher pressures.

The Ferranti or reheating cycle has come into vogue as a practical cycle for turbine operation. The steam is generated at constant pressure and superheat as in the Rankine cycle and is then reheated to the original temperature after passing through the upper stages of a turbine. The steam is then returned to a turbine to complete its expansion. For the same operating conditions as given in the Rankine cycle the data in Table XIV are given for the maximum theoretical efficiency of the reheating cycle:

TABLE XIV.—THEORETICAL EFFICIENCIES OF THE FERRANTI CYCLE

Throttle Pressure, Pounds per Square Inch	Theoretical Efficiency
300	36.5
400	37.7
500	38.4
600	39.1
700	39.7
800	40.1
1,000	40.9
1,200	41.2

This cycle is approximately 1 per cent better than the Rankine cycle efficiencies for the conditions given. But the reduction in water condensation due to reheating should give this cycle marked superiority over the Rankine as an operating cycle. This con-

densation should be reduced about two-thirds with the reheating cycle if high pressures are used.

Roughly, the theoretical best pressure for reheating is about one-third the initial pressure and decreases as the temperature

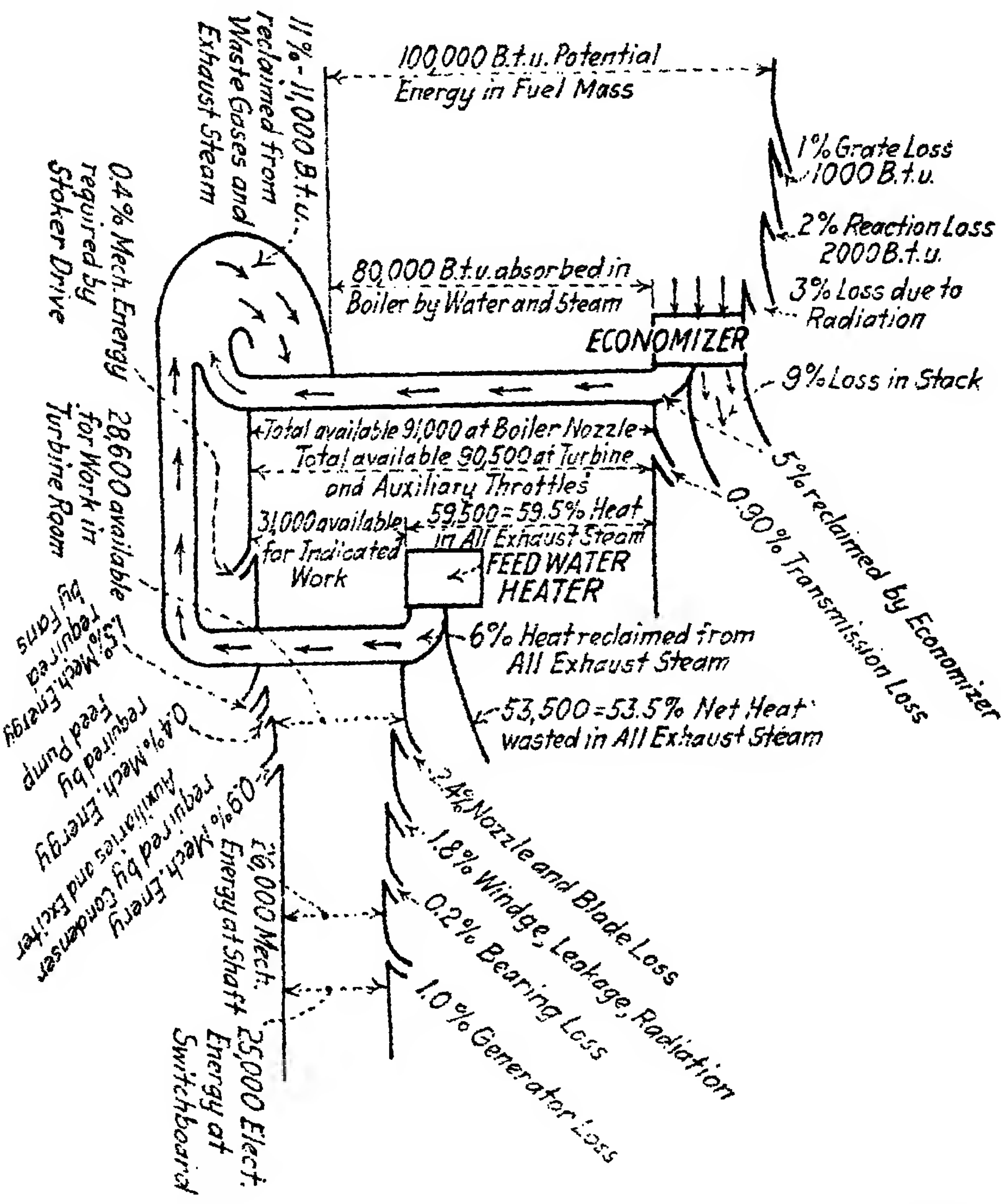

FIG. 47.—Heat stream in an efficient station. Overall thermal efficiency $= \frac{25,000}{100,000} = 25$ per cent. B.t.u. per kilowatt-hour based on 14,000 B.t.u. coal $=$ 0.975 lb. B.t.u. per kilowatt-hour $= \frac{0.3411}{0.25} = 13,650$. All energy percentages refer to the energy in the fuel. (*W. J. Wohlenberg, Yale University.*)

increases. A study shows that this cycle should be improved greatly if the steam could be kept superheated throughout the expansion by having heat added to the steam while in the turbine, but no practical method has been proposed for getting the desired result.

The regenerative Rankine cycle or bleeder-heating cycle is coming rapidly to the front as a practical operating system for larger turbines using high-pressure steam. Steam is taken from lower stages of the turbine to heat the condensate. Assuming an infinite number of heaters and that the feed water is heated to a temperature corresponding to the saturated steam in the turbine, the data in Table XV give the theoretical efficiencies obtainable for various pressures:

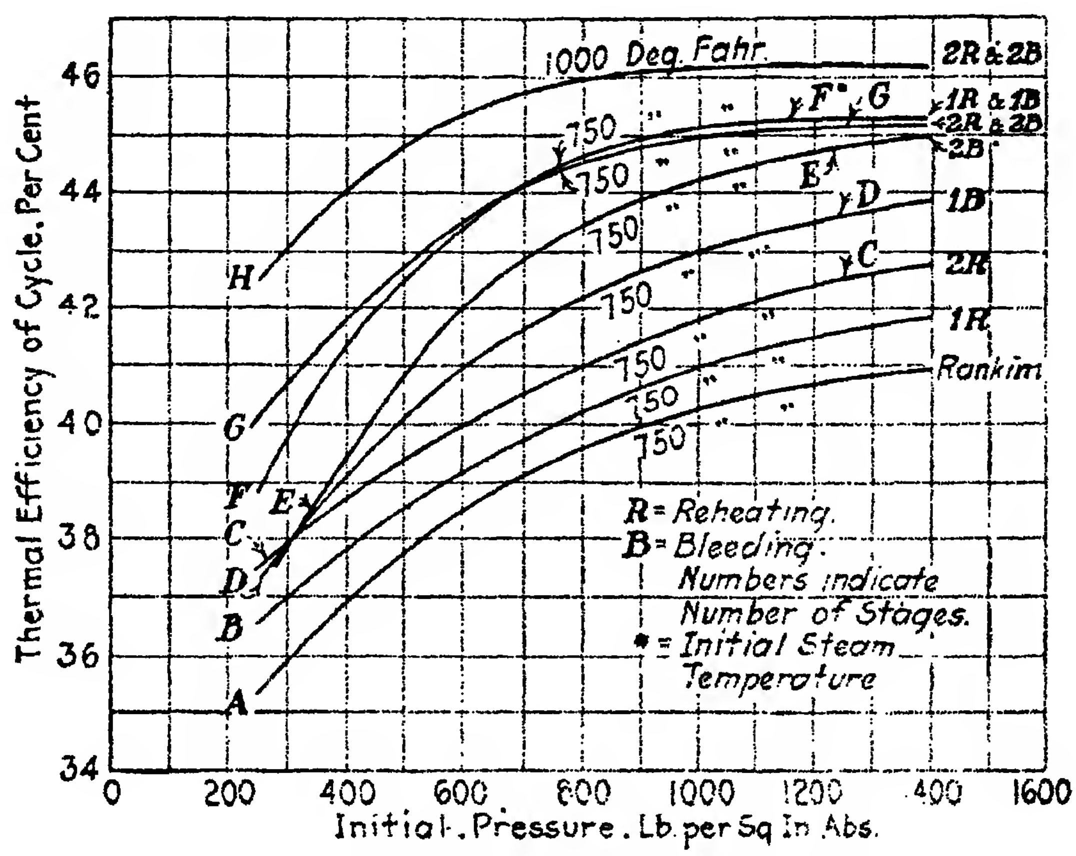

FIG. 48.—Efficiencies of various cycles. Steam conditions, *A* to *F*, inclusive: initial temperature, 750°F.; back pressure, 1 in. Hg. Curve *H*: initial temperature 1000°F.; back pressure, 1 in. Hg. Bleeding points: 240°F. or 25 lb. in one-stage bleeding cycles; 280 and 180°F. or 50 lb. and 7.5 in. Hg in two-stage cycles. (*W. J. Wohlenberg, A.S.M.E.*, 1923.)

TABLE XV.—THEORETICAL EFFICIENCIES OF THE REGENERATIVE RANKINE CYCLE

Throttle Pressure, Pounds per Square Inches	Theoretical Efficiency
300	39.8
400	41
500	42.1
600	43.2
700	44.2
800	45.1
1,000	46.6
1,200	47.8

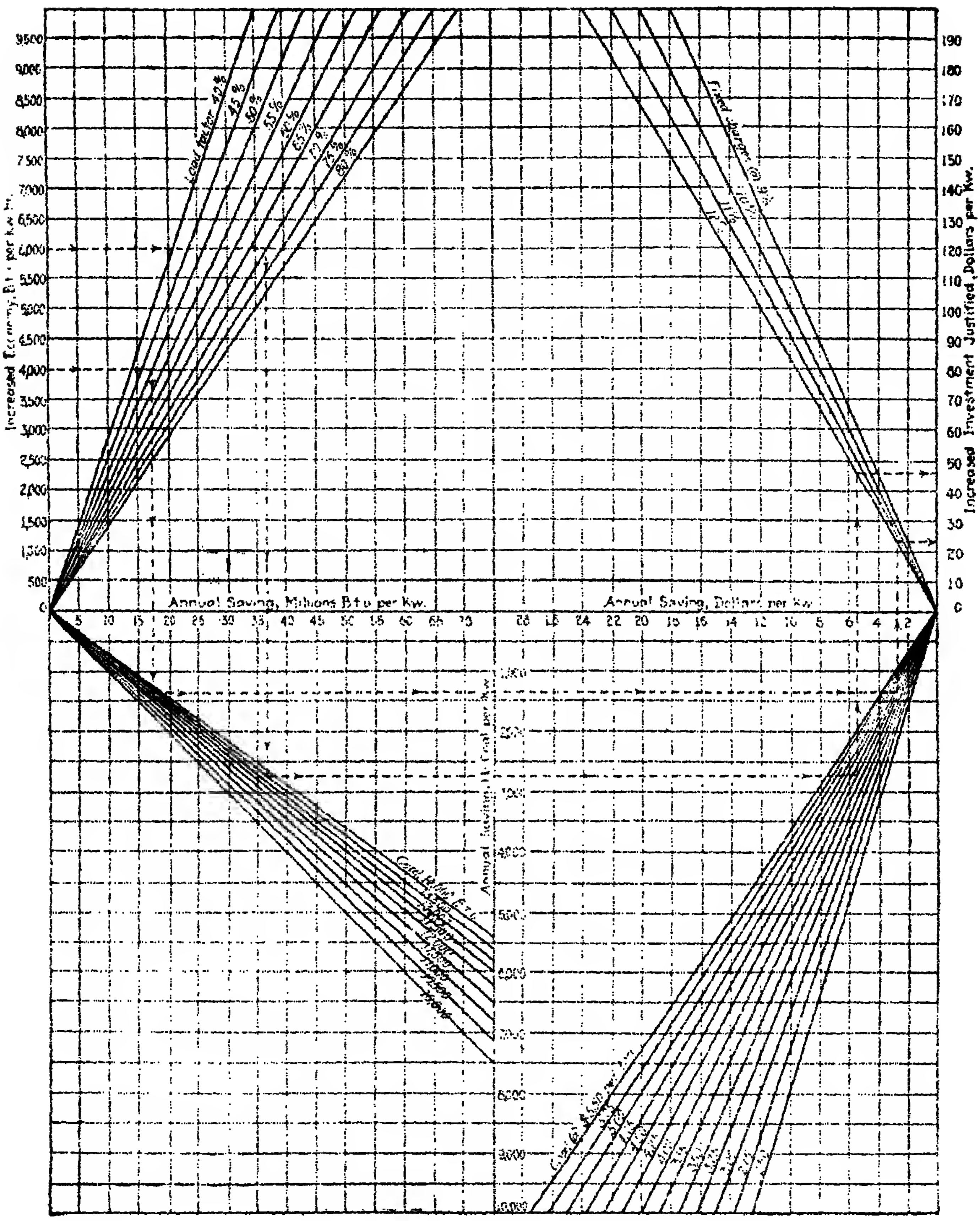

FIG. 49.—Cost of capacity versus thermal economy. The curves have been worked out to show the cost per kilowatt of station capacity justified by a given gain in the thermal efficiency taking into account the B.t.u. per kilowatt-hour saved, the load factor, the B.t.u. per pound of coal as fired and the cost of coal per ton fired to the furnace. Example: If a saving of 6,000 B.t.u. per kilowatt-hour is assumed per kilowatt-hour output, a 70 per cent load factor, coal at 13,500 B.t.u. per pound and costing $4 per ton with 12 per cent fixed charges, the curves show that $46 per kilowatt could be spent to obtain the increased thermal efficiency. (*C. W. De Forest, Electrical World, Sept. 26, 1925.*)

The theoretical efficiency of this cycle for pressures of 500 lb. and above is very high, but as an operating cycle these efficiencies cannot be realized, because a finite number of heaters are used and because water forms in the lower stages of the turbine and other turbine and heater losses occur. A water separator would greatly aid this cycle in realizing its theoretical possibilities as would also the raising of the feed water to a higher temperature than the limit considered.

A cycle adopted for several high-pressure plants combines reheating with regeneration. The steam at high pressure is expanded part way and then resuperheated and in addition stage bleeding is used to heat the condensate. On the assumption of an infinite number of bleeding points and that the condensate is heated to a temperature corresponding to the saturated steam, the data in Table XVI give the theoretical efficiencies of this cycle:

TABLE XVI.—THEORETICAL EFFICIENCIES OF REGENERATIVE AND REHEATING CYCLE

Throttle pressure, pounds per square inch	Best reheating pressure	Theoretical efficiency
300	186	39.1
400	325	40.9
500	420	42.2
600	580	43.2
700	690	45.6
800	800	45.1
1,000	1,000	46.5
1,200	1,200	47.8

For the assumptions used, reheating is not desirable for pressures exceeding about 600 lb., but if the condensate is heated to a higher temperature than that corresponding to the saturated steam in the expansion stages the pressure limit can be raised. Also the presence of water and the effect of losses would tend to increase the pressure at which reheating would be desirable. A general study of the reheating cycle shows that the theoretical efficiency gain is slight, but that the possibility of operating advantages and decreased indirect and turbine losses may make it commercially desirable.

The regenerative cycle is becoming popular because it substitutes the main unit for the house turbine to heat the feed water and thus utilizes a machine that has a higher efficiency. With stage bleeding, about four steps are used, and the steam extracted from the successively higher stages for heating the feed water has done some work before extraction, and if the final temperature of the feed water is the same as in a station using house turbines exhausting into feed heaters, all the steam used in feed-water heating taken from the main unit has worked at a slightly higher efficiency than would be possible in the present house turbines.

The limiting feature in utilizing the regenerative cycle lies in the necessity of limiting the possible number of feed-water heaters because of the cost and complexity and because when economizers are used there is a practical limit to the temperature to which the feed water can enter the economizer and still absorb heat from the waste gases. This temperature for plants operating at about 500 lb. is 300°F. or less, but if the air heaters are used instead of the economizers it may well come about that most of the feed-water heating will be done by stage bleeding and economizers will be eliminated or supplemented.

A proposed variation in the regenerative and reheating cycle also affords possibilities. In this system high-pressure boiler bleeding is used to reheat the main unit steam and then passes to the last stage of the condensate heaters for bringing the feed-water temperature almost to the boiler-water temperature. A little study shows almost an infinite variety of regenerative and reheating combinations and only actual field data can determine which is best to use in practice. All of the schemes present great difficulties but, on the whole, the Rankine regenerative cycle offers good possibilities for commercial applications on the basis of balancing costs and efficiencies if an adequate water separator can be developed, as does also the combined regenerative and reheating cycle if reheating can be done economically and easily.

The possibilities of the numerous cycles proposed must await further operating data for proofs of conclusions and for the final determination of their relative theoretical and practical merits.[1]

[1] Wohlenberg, W. J., "Reheating in Central Stations," A.S.M.E., 1923. Hirshfeld, C. F., and Ellenwood, F. O., "High Pressure, Reheating and Regeneration for Steam Power Plants," A.S.M.E., 1923. Also see "Higher Pressures and Temperatures," by Prime Movers Committee of N.E.L.A., July, 1915, and *Electrical World*, Sept. 26, 1925.

TABLE XVII.—OPERATING COSTS, MAINTENANCE COSTS AND PERFORMANCE DATA ON AMERICAN COAL-BURNING STATIONS[1]

Number of plant	Section of country in which plant is located	Twelve-month period for which data apply (ending)	Installed generator rating, kilowatts (between)	Annual plant use factor, per cent [e]	Net annual output, kilowatt-hours (approximate)	Peak load, kilowatts	Annual fuel consumption, short tons	Annual load factor, per cent [f]	Average B.t.u. per pound of coal	Average ash, per cent	Cost of coal per million B.t.u.	Average price of fuel delivered per net ton	Pounds of fuel per net kilowatt-hour
1	East	Dec. 31, 1924	180,000–200,000	44.0	662,300,000	178,000	510,795	42.0	13,893	9.66	$0.206	$5.72	1.54
2	Central	Dec. 31, 1924	180,000–200,000	45.1	740,600,000	176,800	681,058	47.8	10,347	14.50	0.196	4.05	1.85
3	East	Dec. 31, 1924	180,000–200,000	31.8	518,900,000	162,500	405,148	36.5	14,556	7.20	0.181	5.25	1.56
4	East	Dec. 31, 1924	180,000–200,000	40.0	640,750,000	163,000	419,077	45.0	14,161	6.53	0.184	5.20	1.31
5	Central	May 31, 1925	180,000–200,000	42.8	674,900,000	161,500	508,445	47.7	13,198	7.60	0.150	3.96	1.51
6	East	Dec. 31, 1924	130,000–180,000	23.9	346,750,000	131,000	273,388	[a]30.2	13,867	7.60	0.171	4.77	1.57
7	Central	[b]May 31, 1925	130,000–180,000	50.6	127,150,000	93,200	101,503	64.0	10,332	14.50	0.190	3.92	1.60
8	Central	[c]May 31, 1925	130,000–180,000	33.0	179,250,000	99,700	108,551	49.6	13,824	6.60	0.141	3.91	1.21
9	East	Dec. 31, 1924	[d]130,000–180,000	62.0	816,800,000	156,000	575,467	59.6	13,090	9.50	0.115	3.02	1.41
10	Central	Apr. 30, 1925	[e]100,000–130,000	38.0	432,600,000	112,000	275,975	44.1	12,796	10.00	0.186	4.76	1.28
11	Central	May 31, 1925	100,000–130,000	39.1	323,950,000	94,200	307,818	39.3	13,198	8.70	0.150	3.96	1.90
12	East	Dec. 31, 1924	100,000–130,000	27.3	282,300,000	77,000	2[illegible]9,411	41.8	14,756	6.00	0.171	5.04	1.77
13	Central	Apr. 30, 1925	100,000–130,000	[g]46.7	363,900,000	94,000	291,352	44.2	10,844	12.20	0.145	3.15	1.60
14	Central	Dec. 31, 1924	100,000–130,000	46.1	403,700,000	110,000	[h]294,841	41.9	12,850	9.50	0.138	3.56	1.46
15	East	Dec. 31, 1924	70,000–100,000	18.4	153,000,000	92,000	163,418	[a]19.0	12,640	11.00	0.176	4.46	2.14
16	East	Dec. 31, 1924	70,000–100,000	15.3	121,500,000	48,800	99,032	29.0	14,500	6.00	0.224	6.49	1.63
17	Central	Dec. 31, 1924	70,000–100,000	38.8	306,000,000	68,500	283,566	51.0	10,000	16.10	0.207	4.14	1.85
18	Central	Dec. 31, 1924	70,000–100,000	33.5	219,500,000	72,000	209,377	39.5	12,577	12.01	0.136	3.42	1.68
19	Central	Dec. 31, 1924	70,000–100,000	28.0	206,800,000	50,400	282,688	46.0	9,519	15.48	0.153	2.91	2.48
20	South	Dec. 31, 1924	70,000–100,000	32.7	200,600,000	78,500	198,031	[a]29.1	13,100	12.80	0.137	3.61	1.90
21	East	Dec. 31, 1924	50,000– 70,000	26.0	157,400,000	52,000	1[illegible]0,782	31.5	14,000	.....	0.178	4.99	1.71
22	South	Dec. 31, 1924	50,000– 70,000	30.8	1[illegible]2,300,000	48,700	176,364	41.7	11,592	13.82	0.140	3.25	1.93
23	Central	Dec. 31, 1924	50,000– 70,000	29.8	175,100,000	46,000	225,518	43.4	12,975	10.41	0.157	4.07	2.58
24	East	Dec. 31, 1924	50,000– 70,000	11.9	6,750,000	32,800	131,301	[a]22.8	13,500	10.00	0.1335	4.68	2.37
25	South	Dec. 31, 1924	50,000– 70,000	3.1	16,350,000	46,000	14,650	[a]4.1	14,300	6.00	0.160	4.58	1.70
26	Central	Dec. 31, 1924	50,000– 70,000	56.0	294,200,000	59,000	296,445	56.9	12,257	12.17	0.130	2.98	2.02
27	East	Dec. 31, 1924	50,000– 70,000	17.9	89,250,000	28,900	84,482	35.2	13,894	7.59	0.235	6.52	1.88
28	East	Dec. 31, 1924	50,000– 70,000	12.4	69,000,000	32,590	65,399	[a]21.0	14,300	7.10	0.225	6.38	2.01
29	South	Dec. 31, 1924	50,000– 70,000	31.8	148,000,000	50,500	180,000	33.4	12,498	.....	0.101	2.54	2.32
30	Central	May 31, 1925	50,000– 70,000	51.7	226,550,000	58,700	168,537	44.1	12,687	11.50	0.167	4.26	1.49
31	Central	Dec. 31, 1924	50,000– 70,000	35.2	154,850,000	35,200	192,612	49.9	10,905	.....	0.1238	2.70	2.42
32	Central	Dec. 31, 1924	50,000– 70,000	38.0	166,600,600	42,000	143,808	45.3	10,869	11.30	0.210	4.56	1.73
33	Central	Dec. 31, 1924	35,000– 50,000	41.8	176,800,000	43,000	211,037	46.9	12,600	11.00	0.1142	2.88	2.39
34	East	Dec. 31, 1924	35,000– 50,000	35.4	135,150,000	37,800	124,020	40.8	13,850	8.80	0.1355	3.74	1.84
35	South	Dec. 31, 1924	35,000– 50,000	26.6	93,000,000	24,200	93,071	47.0	14,500	7.00	0.170	4.93	1.73
36	Central	Dec. 31, 1924	35,000– 50,000	34.3	127,300,000	53,500	193,180	28.0	11,000	13.00	0.113	2.49	3.03

37	Central...	Dec. 31, 1924	35,000– 50,000	34.2	108,700,000	34,000	138,770	[a]34.8	10,651	16.70	0.1535	3.27	2.55
38	East......	Dec. 31, 1924	35,000– 50,000	23.4	81,950,000	21,000	69,544	44.6	13,765	.....	0.203	5.58	1.70
39	East......	Dec. 31, 1924	35,000– 50,000	29.2	102,100,000	40,000	80,187	29.2	13,914	7.00	0.241	6.71	1.57
40	East......	Dec. 31, 1924	35,000– 50,000	23.1	77,200,000	19,500	98,914	45.1	10,500	.....	0.1052	2.21	2.56
41	East......	Dec. 31, 1924	35,000– 50,000	14.9	47,100,000	30,700	49,467	[m]17.5	14,083	7.00	0.2385	6.71	2.10
42	Central...	Dec. 31, 1924	35,000– 50,000	22.8	[n]99,850,000	23,200	97,794	49.1	10,438	13.20	0.1523	3.18	2.76
43	Central...	Dec. 31, 1924	35,000– 50,000	18.0	55,250,000	16,400	89,872	38.5	11,000	15.00	0.1676	3.69	2.50
44	Central...	Dec. 31, 1924	25,000– 35,000	6.9	20,650,000	15,000	96,249	15.7	10,750	.....	0.1276	2.77	4.17
45	East......	Dec. 31, 1914	25,000– 35,000	17.1	48,800,000	25,200	46,179	22.1	13,797	8.09	0.2088	5.76	1.89
46	East......	Apr. 30, 1925	25,000– 35,000	21.9	59,700,000	20,000	88,852	34.1	12,000	.....	0.1666	4.00	2.97
47	Central...	Dec. 31, 1924	25,000– 35,000	28.9	78,350,000	22,200	86,089	40.3	11,176	15.16	0.165	3.69	2.19
48	East......	Dec. 31, 1924	25,000– 35,000	26.2	69,000,000	32,400	77,591	[a]25.0	10,700	17.00	0.1972	4.22	2.25
49	East......	Dec. 31, 1924	25,000– 35,000	16.2	42,650,000	15,600	53,349	31.2	12,544	13.90	0.1778	4.46	2.50
50	South....	Dec. 31, 1924	25,000– 35,000	14.0	37,750,000	28,000	57,488	[a]14.8	11,500	.....	0.1112	2.56	3.05
51	Central...	Dec. 31, 1924	25,000– 35,000	38.4	87,450,000	23,500	153,617	46.1	10,000	20.90	0.1645	3.29	3.51
52	Central...	Dec. 31, 1924	25,000– 35,000	36.2	88,900,000	11,750	116,135	86.4	11,047	.....	0.1632	3.61	2.61
53	East......	Dec. 31, 1924	25,000– 35,000	33.3	80,100,000	25,000	72,586	36.57	14,586	7.49	0.2023	5.90	1.79
54	Central[e]..	Dec. 31, 1924	25,000– 35,000	45.1	98,700,000	26,000	84,688	43.30	10,906	11.70	0.2007	4.58	1.72
55	East......	Dec. 31, 1924	15,000– 25,000	19.5	40,500,000	15,155	37,024	30.5	14,259	13.70	0.2322	6.63	1.83
56	East......	Dec. 31, 1924	15,000– 25,000	17.0	34,500,000	10,120	39,985	39.0	13,800	8.50	0.1914	5.28	2.22
57	South....	Dec. 31, 1924	15,000– 25,000	24.9	49,000,000	17,800	[p]44,724	32.6	11,568	16.81	0.2743	3.17	2.02
58	East......	Feb. 28, 1925	15,000– 25,000	34.0	63,500,000	16,400	60,931	44.0	13,674	11.00	.....	.....	2.04
59	Central...	Jan. 31, 1925	15,000– 25,000	45.5	40,000,000	12,500	58,700	36.0	11,500	16.00	0.1552	3.57	2.93
60	Central...	Dec. 31, 1924	15,000– 25,000	35.0	64,650,000	16,500	[q]93,398	48.2	10,393	16.00	0.1723	3.58	3.19
61	Central...	Dec. 31, 1924	15,000– 25,000	13.4	23,600,000	8,400	29,816	32.0	11,500	.....	0.222	5.11	2.54
62	East......	Dec. 31, 1924	15,000– 25,000	24.6	45,750,000	14,775	43,507	35.30	14,000	11.00	0.2155	6.04	2.21
63	East......	Dec. 31, 1924	15,000– 25,000	28.2	47,000,000	14,100	44,237	38.05	14,396	6.76	0.2318	6.67	1.88
64	East......	Dec. 31, 1924	15,000– 25,000	9.8	16,150,000	11,600	15,910	[a]15.86	14,750	5.75	0.2092	6.17	1.97
65	East......	Dec. 31, 1924	15,000– 25,000	10.7	16,400,000	7,000	19,766	26.80	14,200	7.00	0.2192	6.23	2.41
66	West.....	Aug. 31, 1924	15,000– 25,000	37.2	53,600,000	16,900	74,807	36.20	9,500	5.00	0.122	2.32	2.79
67	East......	Dec. 31, 1924	15,000– 25,000	21.8	31,500,000	14,800	44,900	[a]24.29	13,157	10.62	0.202	5.31	2.85
68	Central...	Dec. 31, 1924	15,000– 25,000	15.8	17,250,000	10,700	28,238	[m]18.40	11,662	16.53	0.1415	3.29	3.27
69	East......	Dec. 31, 1924	15,000– 25,000	56.6	79,250,000	16,800	59,793	53.80	13,700	9.00	0.1635	4.48	1.51
70	East......	Dec. 31, 1924	15,000– 25,000	18.7	25,450,000	8,000	27,400	46.89	14,500	6.50	0.2385	6.92	2.15
71	East......	Dec. 31, 1924	15,000– 25,000	9.3	12,650,000	15,700	14,960	[a]9.20	14,500	6.00	0.2592	7.52	2.36
72	West.....	Dec. 31, 1924	15,000– 25,000	60.5	79,600,000	17,750	88,312	51.19	11,750	13.00	0.1285	3.02	2.22
73	South....	Dec. 31, 1924[t]	15,000– 25,000	28.6	15,650,000	20,000	19,532	21.20	11,422	15.90	0.1411	3.23	2.49
74	Central[u]..	Dec. 31, 1924	10,000– 15,000	45.7	54,900,000	13,000	86,710	45.70	11,300	.....	0.2355	5.28	3.16
75	South....	Dec. 31, 1924	10,000– 15,000	33.7	39,750,000	12,500	39,720	36.40	14,000	8.40	0.177	4.96	1.99
76	East......	Dec. 31, 1924	10,000– 15,000	14.0	16,000,000	5,400	17,355	34.00	13,881	9.13	0.283	7.87	2.16
77	Central...	Dec. 31, 1924	10,000– 15,000	17.2	15,500,000	......	23,976	.....	......	.....	......	2.29	2.96
78	Central ..	July 1, 1924	10,000– 15,000	33.6	30,000,000	6,700	45,254	51.00	14,000	6.01	0.1764	4.94	3.02
79	Central. .	Dec. 31, 1924	10,000– 15,000	40.1	35,100,000	11,400	41,578	35.20	14,000	9.00	0.172	4.82	2.37
80	South....	Dec. 31, 1924	10,000– 15,000	26.1	22,850,000	6,500	30,829	40.10	13,200	.....	0.1919	5.07	2.70
81	South....	Dec. 31, 1924	10,000– 15,000	16.9	19,350,000	13,200	26,496	[a]16.70	13,300	11.00	0.1431	3.81	2.60
82	Central...	Dec. 31, 1924	7,500– 10,000	26.3	21,850,000	5,600	22,940	44.5	12,830	11.50	0.0935	2.40	2.10

TABLE XVII.—OPERATING COSTS, MAINTENANCE COSTS AND PERFORMANCE DATA ON AMERICAN COAL-BURNING STATIONS.[1]—(*Continued*)

Number of plant	Section of country in which plant is located	Twelve-month period for which data apply (ending)	Installed generator rating, kilowatts (between)	Annual plant use factor, per cent[d]	Net annual output, kilowatt-hours (approximate)	Peak load, kilowatts	Annual fuel consumption, short tons)	Annual load factor, per cent[f]	Average B.t.u. per pound of coal	Average ash, per cent	Cost of coal per million B.t.u.	Average price of fuel delivered per net ton	Pounds of fuel per net kilowatt-hour
83	Central	Dec. 31, 1924	7,500– 10,000	23.0	19,300,000	5,750	31,317	38.0	13,200	4.50	$0.1525	$1.03	3.07
84	South	Dec. 31, 1924	7,500– 10,000	24.6	19,480,000	10,500	21,799	21.1[a]	14,000	6.50	0.166	4.65	2.24
85	Central[z]	Apr. 30, 1925	7,500– 10,000	33.1	17,920,000	5,200	42,343	39.3	11,500	13.50	0.2009	4.62	4.84
86	East	Nov. 30, 1924	7,500– 10,000	30.6	23,500,000	7,600	21,684	35.2	......	.....	......	6.75	2.25
87	West	Dec. 31, 1924	7,500– 10,000	41.4	30,900,000	6,314	38,860	55.8	12,750	15.00	0.1498	3.84	2.51
88	West	Dec. 31, 1924	7,500– 10,000	20.0	15,300,000	7,300	35,000	25.0	10,500	8.00	0.131	2.75	4.00
89	South	Dec. 31, 1924	7,500– 10,000	7.9	5,590,000	7,500	6,761	8.5[a]	13,500	8.00	0.1306	3.53	2.42
90	Central	Dec. 31, 1924	7,500– 10,000	12.2	8,500,000	5,800	20,233	16.7[a]	11,500	.....	0.1678	3.86	3.66
91	Central	Dec. 31, 1924	7,500– 10,000	11.8	7,800,000	8,129	9,975	12.7[a]	12,500	9.00	0.2138	5.35	2.55
92	East	Dec. 31, 1924	5,000– 7,500	20.0	16,740,000	5,700	16,287	25.0	14,617	7.13	0.217	6.35	2.57
93	East	Dec. 31, 1924	5,000– 7,500	34.0	21,450,000	6,800	25,138	36.0	13,932	12.70	0.1635	4.56	2.34
94	Central	Dec. 31, 1924	5,000– 7,500	30.0	18,250,000	4,050	26,313	50.0	11,500	15.00	0.1169	2.69	2.80
95	Central	Dec. 31, 1924	5,000– 7,500	14.1	15,130,000	4,500	26,532	38.4	9,864	13.58	0.239	4.71	3.50
96	Central[t]	Dec. 31, 1924	5,000– 7,500	27.4	12,820,000	....	15,250	....	14,515	.....	0.205	5.95	2.38
97	South[g]	Dec. 31, 1924	5,000– 7,500	7.4	3,240,000	2,000	30,303[a']	18.5[a]	13,300	8.00	0.1405	3.74	
98	Central	Dec. 31, 1924	3,000– 5,000	29.4	12,220,000	4,180	13,981	33.4	14,000	9.00	0.2135	5.98	2.29
99	East	Dec. 31, 1924	3,000– 5,000	36.5	13,120,000	3,700	16,917	41.4	14,400	4.50	0.1574	4.53	2.52
100	East	Dec. 31, 1924	3,000– 5,000	14.0	5,340,000	4,000	7,379	15.0[a]	......	.....	......	4.85	2.76
101	West	Dec. 31, 1924	3,000– 5,000	18.8	6,650,000	2,100	2,556[b']	41.6	12,000	9.00	0.255	6.12	3.40
102	Central	Dec. 31, 1924	3,000– 5,000	16.6	5,750,000	2,000	7,080	29.0	13,120	6.50	0.1895	4.98	2.78
103	West	Dec. 31, 1924	3,000– 5,000	28.4	8,870,000	3,054	15,275	34.9	12,750	15.00	0.1075	2.74	3.44
104	Central	Dec. 31, 1924	3,000– 5,000	46.1	12,110,000	3,450	11,907	40.1	13,000	10.00	0.2575	6.70	1.96
105	Central	Dec. 31, 1924	2,000– 3,000	20.4	5,190,000	1,900	8,910	31.1	14,000	7.10	0.177	4.96	3.43
106	Central	Dec. 31, 1924	2,000– 3,000	29.0	7,000,000	3,200	12,863	25.0	12,500	9.00	0.160	4.00	3.67
107	South	Dec. 31, 1924	2,000– 3,000	16.6	4,000,000	3,000	8,853	15.2	11,500	11.00	0.1725	5.00	2.50
108	East	Dec. 31, 1924	2,000– 3,000	19.0	5,775,000	2,200	12,937	30.0	13,500	12.00	0.1595	4.31	4.40
109	East	Dec. 31, 1924	2,000– 3,000	27.2	6,210,000	1,100	13,700	64.4	......	.....	......	2.20	4.50
110	East	Dec. 31, 1924	2,000– 3,000	20.0	3,610,000	1,500	4,158	30.0	14,000	11.00	0.172	4.82	2.25
111	South	Dec. 31, 1924	2,000– 3,000	18.8	4,115,000	1,250	10,220	37.6	11,000	12.00	0.175	3.85	4.97
112	East	Dec. 31, 1924	2,000– 3,000	29.8	6,515,000	2,220	13,597	33.4	11,547	7.30	0.206	6.00	4.17
113	West	Dec. 31, 1924	2,000– 3,000	29.8	6,160,000	1,600	16,679	46.5	12,000	4.00	0.0745	1.79	5.41
114	East	Dec. 31, 1924	2,000– 3,000	39.0	8,010,000	2,750	19,463	33.3	14,400	7.05	0.1846	5.32	4.86
115	Central	Dec. 31, 1924	2,000– 3,000	13.8	2,725,000	2,200	4,922	14.2[a]	13,500	6.00	0.236	6.37	3.62
116	Central	Dec. 31, 1924	2,000– 3,000	20.5	3,640,000	1,100	5,400	39.8	11,800	5.00	0.1652	3.90	2.96

117	Central...	Dec. 31, 1924	1,000– 2,000	21.7	3,400,000	900	5,277	43.1	11,066	22.10	0.1995	4.41	3.10
118	Central...	Dec. 31, 1924	1,000– 2,000	19.0	2,965,000	1,050	1,928	32.0	......	.....	....	6.00	4.50
119	South[d']...	Dec. 31, 1924	1,000– 2,000	15.0	2,070,000	790	6,433	30.0	13,000	7.00	0.202	5.25	6.22
120	Central...	Dec. 31, 1924	1,000– 2,000	24.2	2,730,000	1,500	6,980	24.8	......	.....	....	3.67	5.12
121	Central...	Dec. 31, 1924	1,000– 2,000	49.2	6,470,000	2,000	15,755	36.9	11,930	8.40	0.2275	5.44	4.40
122	South....	Dec. 31, 1924	1,000– 2,000	22.3	2,440,000	870	7,996	32.0	12,000	.....	0.1672	4.01	6.54
123	Central...	Feb. 28, 1925	1,000– 2,000	14.3	1,440,000	700	3,395	23.4	......	.....	....	4.97	4.70
124	East......	Dec. 31, 1924	1,000– 2,000	28.1	3,200,000	1,080	5,379	33.8	14,450	7.00	0.2246	6.50	3.36
125	West.....	Dec. 31, 1924	1,000– 2,000	37.5	3,615,000	1,290	9,637	32.0	11,000	13.00	0.1022	2.25	5.33
126	West.....	Dec. 31, 1924	1,000– 2,000	14.0	1,255,000	480	3,595	30.8	12,500	14.50	0.1962	4.91	5.73
127	West.....	Dec. 31, 1924	Below 1,000	25.7	1,855,000	600	4,442	35.2	13,000	13.50	0.2495	6.75	4.77
128	West.....	Dec. 31, 1924	Below 1,000	19.6	1,550,000	527	4,953	33.6	12,000	10.00	0.147	3.53	6.40
129	West.....	Dec. 31, 1924	Below 1,000	12.2	775,500	295	2,097	30.0	12,800	7.00	0.250	6.40	5.00
130	Central...	Oct. 31, 1924	Below 1,000	19.0	756,000	300	3,872	29.0	10,424	13.35	0.130	2.75	10.20
131	Central...	Dec. 31, 1924	Below 1,000	13.0	492,000	230	2,868	24.0	11,000	.....	0.1475	3.25	11.50
132	West.....	Dec. 31, 1924	Below 1,000	13.2	382,000	132	2,157	33.0	......	.....	....	4.21	9.60
133	Central...	Dec. 31, 1924	Below 1,000	27.1	755,000	190	1,947	45.4	11,000	.....	0.1295	2.85	5.16
134	Central...	Dec. 31, 1924	Below 1,000	12.0	290,000	100	1,100	33.0	14,000	6.00	0.1303	3.65	8.00
135	South....	Dec. 31, 1924	Below 1,000	20.7	453,000	150	2,795	34.4	14,000	10.00	0.1785	5.00	10.00
136	Central...	Dec. 31, 1924	Below 1,000	30.2	595,000	230	3,000	29.5	13,000	7.00	0.250	6.50	10.00

[1] *Electrical World*, Sept. 26, 1925.

[a] Operated in system having hydro-electric plants.

[b] Four-month period.

[c] Five-month period.

[d] 30,000-kw. unit in commission Sept. 19, 1924

[e] 30,000-kw. unit in commission Nov. 30, 1924.

[f] Includes generators and electrical equipment.

[g] Two-thirds of capacity added during 1924.

[h] Natural gas used part of time; figure given is coal and gas equivalent in terms of coal.

[i] Includes prime movers, auxiliaries, generators and electrical equipment.

[j] Includes miscellaneous.

[k] Includes boiler plant.

[l] Includes generators, electrical equipment and miscellaneous

[m] Standby to newer steam plant.

[n] Includes some purchased energy, expenses based on energy generated only.

[o] With additional 35,000-kw. unit this plant over a month's period operated at load factor of 58 per cent, 17,200 B.t.u. per kilowatt-hour, and total operating (0.402) and maintenance (0.017) expense of 0.419 cts.

[p] Used 6,985 bbl. oil, also included in expenses.

[q] Used 38,919 bbl. oil at 143,099 B.t.u. per gallon.

[r] Current purchased and miscellaneous expenses.

[s] Includes water, lubrication, supplies and miscellaneous.

[t] In operation Aug. 1, 1924.

[u] Two plants combined.

[v] Includes steam heating system cost prorated at 0.165 ct. per kilowatt-hour.

[w] Includes prime movers and auxiliaries.

[x] Includes 86,324,000 lb. of steam heat: 420,200 kw.-hr. was generated by three small Diesel engines, the fuel expenses of which are not included.

[y] Includes maintenance.

[z] Includes separate station of 1,000 kw. seldom used.

[a'] Steam heating system included.

[b'] 81 per cent of energy generated with wood refuse.

[c'] Includes water, lubrication and supplies.

[d'] Reciprocating engine replaced by turbo-generator Nov. 7, 19t4

[e'] Annual plant use factor $= \dfrac{\text{Net kilowatt-hour}}{\text{Kilowatt installed} \times 8{,}760}$

[f'] Annual load factor $= \dfrac{\text{Net kilowatt-hour}}{\text{Peak load (kilowatt)} \times 8{,}760}$

TABLE XVII.—OPERATING COSTS, MAINTENANCE COSTS AND PERFORMANCE DATA ON AMERICAN COAL-BURNING STATIONS.[1]—(*Continued*)

Number of plant	Section of country in which plant is located	B.t.u. per net kilowatt hour	Detail operating expenses, cents: Fuel	Detail operating expenses, cents: Wages and superintendence	Detail operating expenses, cents: Water lubrication and supplies	Detail operating expenses, cents: Miscellaneous	Detail operating expenses, cents: Total	Detail maintenance expenses, cents: Building and structures	Detail maintenance expenses, cents: Boiler plant	Detail maintenance expenses, cents: Prime movers and auxiliaries	Detail maintenance expenses, cents: Generators and electric equipment	Detail maintenance expenses, cents: Miscellaneous	Detail maintenance expenses, cents: Total	Total operating and maintenance expense, cents	Date of initial operation
1	East	20,826	0.4413	0.0746	0.0088	0.0052	0.5299	0.0120	0.0329	0.0125	0.0094	0.0012	0.0680	0.5979	1915
2	Central	18,824	0.367	0.036	0.005	......	0.408	0.004	0.013	0.013	0.004	......	0.034	0.442	1921
3	East	21,910	0.4124	0.0666	0.0151	......	0.4941	0.0084	0.0451	0.0083	0.0093	0.0087	0.0798	0.5739	1906
4	East	18,551	0.359	0.071	0.005	0.009	0.444	0.008	0.041	0.010	0.010	0.003	0.072	0.516	1921
5	Central	20,114	0.32	0.07	0.01	......	0.40	0.01	0.03	0.01	0.01	0.01	0.07	0.47	1915
6	East	21,866	0.381	0.073	0.009	0.006	0.469	0.019	0.041	0.046	0.003	0.002	0.111	0.580	1913
7	Central	16,416	0.312	0.050	0.007	......	0.369	0.004	0.008	0.004	0.003	......	0.019	0.388	1925
8	Central	16,744	0.25	0.08	0.02	......	0.35	0.01	0.02	......	......	......	0.03	0.38	1924
9	East	18,460	0.224	0.044	0.020	0.000	0.288	0.004	0.016	0.006	0.005	0.002	0.033	0.321	1920
10	Central	16,326	0.3030	0.0458	0.0027	0.0021	0.3536	0.0016	0.0252	0.0032[f]	......	0.0011	0.0311	0.3847	1920
11	Central	25,080	0.40	0.17	0.04	......	0.61	0.02	0.06	0.02	0.01	0.01	0.12	0.73	1908
12	East	26,074	0.4526	0.0384	0.0034	0.0058	0.5002	0.0034	0.0232	0.0039	0.0331	0.0009	0.0645	0.5647	1912
13	Central	17,361	0.2523	0.0532	0.0059	0.0005	0.3119	0.0022	0.0214	0.0016	0.0050	......	0.0302	0.3421	1923
14	Central	15,760	......	......	......	......	......	......	......	......	......	......	......	0.4510	1918
15	East	27,000	0.489	0.117	0.005	0.004	0.615	0.011	0.066	0.045	0.001	0.008	0.131	0.746	1916
16	East	23,700	0.4831	0.0851	0.0077	0.0041	0.5800	0.0068	0.0359	......	0.0242	0.0059	0.0728	0.6528	1913
17	Central	18,510	0.385	0.047	0.011	0.005	0.448	0.004	0.028	0.003	0.005	0.004	0.044	0.492	1919
18	Central	21,112	0.3192	0.0432	0.0140	......	0.3767	0.0023	0.0433	0.0154	0.0040	0.0650	0.0650	0.4420	1917
19	Central	23,117	0.4009	0.0963	0.0082	0.0122	0.5176	0.0035	0.0708	0.0091	0.0085	0.0026	0.0945	0.6121	1913
20	South	24,890	0.3570	0.0325	0.0021	0.0081	0.3997	0.0050	0.0234	0.0072	0.0025	0.0134	0.0517	0.4514	1917
21	East	24,000	0.4468	0.1103	0.0041	...	0.5612	0.0104	0.0783	0.0386	0.0133	0.0057	0.1463	0.7055	1910
22	South	22,435	0.315	0.087	0.004	0.014	0.420	0.008	0.065[i]	...	......	0.003	0.076	0.496	
23	Central	33,475	0.522	0.064	0.004	......	0.590	0.002	0.034	0.006	0.002	......	0.044	0.634	1912
24	East	31,995	0.5398	0.2278	0.0115	0.0399	0.8190	0.0358	0.0623	0.0115	0.0048	0.0019	0.1163	0.9353	1912
25	South	21,310	0.4150	0.1067	0.0109	0.0228	0.5554	0.0276	0.0398	0.0482	0.0085	0.0665	0.1906	0.7460	1918
26	Central	24,698	0.3298	0.0683	0.0059	0.0034	0.4074	0.0012	0.0529	0.0091	0.0025	0.0049	0.0706	0.4780	1910
27	East	26,300	0.5525	0.0985	0.467	......	0.6979	0.0353	0.0588	0.0230	0.0291	0.0823	0.2287	0.8843	1910
28	East	28,743	0.6965	0.1616	0.0359	......	0.8940	0.0132	0.0852	0.0251[f]	......	0.0061	0.1297	1.0237	1913
29	South	29,021	0.311	0.057	0.006	0.004	0.378	0.002	0.034	0.011	0.020	0.008	0.075	0.453	1915
30	Central	18,874	0.31	0.09	0.02	......	0.42	0.01	0.03	0.01	0.01	......	0.06	0.48	1922
31	Central	26,420	0.3620	0.1034	0.0054	0.0222	0.4930	0.0118	0.0658	0.0067	0.0053	0.0256	0.1152	0.6082	1905
32	Central	18,803	0.393	0.059	0.003	0.004	0.459	0.001	0.009	0.003	0.029	0.001	0.043	0.502	1918
33	Central	30,143	0.347	0.077	0.017[j]	......	0.441	0.038[k]	......	0.015[l]	......	......	0.053	0.494	1914

34	East......	25,428	0.3430	0.1060	0.0341	0.0158	0.4980	0.0038	0.0407	0.0121	0.0027	0.0068	0.0661	0.5650	1911
35	South.....	25,000	0.4613	0.1114	0.0098	......	0.5825	0.0038	0.0195	0.0107	0.0077	......	0.0417	0.6242	1916
36	Central...	33,330	0.3770	0.2125	0.0171	0.0141	0.6209	0.0157	0.0474	0.0102	0.0280	......	0.1013	0.7220	
37	Central...	26,985	0.4180	0.1100	0.0287	......	0.5567	......	0.0507	0.0166	0.0032	0.0163	0.0868	0.6435	1910
38	East......	23,400	0.423	0.096	0.017	......	0.536	0.001	0.041	0.005	0.005	0.004	0.056	0.592	1923
39	East......	20,811	0.5270	0.0952	0.0093	0.0710	0.7025	0.0134	0.0368	0.0069	0.0027	0.0049	0.0647	0.7672	1921
40	East......	26,901	0.2830	0.1278	0.0122	0.0155	0.4385	0.0042	0.0304	0.0048	0.0024	0.0030	0.0448	0.4833	1915
41	East......	30,228	0.7280	0.2248	0.0161	0.0563	1.0253	0.0208	0.0707	0.0185	0.0078	0.0009	0.1187	1.1440	1918
42	Central...	28,808	0.432	0.093	0.005	0.004	0.536	0.004	0.034	0.021[f]	......	0.04	0.064	0.600	1907
43	Central...	27,500	0.6402	0.1059	0.0287	......	0.7748	0.0369	0.0903	0.0167	0.0345	0.0046	0.1830	0.9578	
44	Central...	44,790	1.362	0.455	0.018	0.138	1.980	0.122	0.358	0.066	0.020	0.054	0.620	2.600	1892
45	East......	26,076	0.531	0.131	0.012	0.005	0.679	0.008	0.061	0.014	0.009	0.005	0.097	0.776	1918
46	East......	35,640	0.6330	0.1472	0.0198	0.0060	0.8060	0.031	0.120	0.040	0.019	......	0.2120	1.018	1910
47	Central...	24,500	0.40	0.12	0.005	0.005	0.53	......	......	......	......	......	0.17	0.70	1913
48	East......	24,100	0.4750	0.1185	0.0038	0.0280	0.6953	0.0137	0.0835	0.0196[f]	......	0.0107	0.1275	0.8228	1921
49	East......	31,371	0.5581	0.1858	0.0172	0.0283	0.7894	0.0160	0.0845	0.0343	0.0056	0.0019	0.1423	0.9317	1917
50	South.....	35,075	0.3890	0.1392	0.0243	0.0537	0.6062	0.0142	0.0578	0.0011	0.0011	0.0030	0.0972	0.7034	1902
51	Central...	35,100	0.5777	0.1394	0.0283	0.0190	0.7644	......	0.1227	0.0450[f]	......	......	0.1677	0.9321	1913
52	Central...	28,833	0.471	0.102	0.008	0.006	0.587	0.013	0.057	0.003	0.014	0.009	0.096	0.683	
53	East......	24,923	0.5350	0.1053	0.0498	0.0139	0.7040	0.0032	0.0578	0.0065	0.0045	0.0118	0.0838	0.7878	1916
54	Central[e]..	18,758	0.393	0.096	0.006	0.008	0.503	0.001	0.014	0.003	0.004	0.003	0.025	0.528	1923
55	East......	26,094	0.634	0.183	0.036	......	0.853	0.028	0.036	0.027	0.021	0.004	0.116	0.969	1907
56	East......	30,636	0.6124	0.1303	0.0151	0.0128	0.7705	0.0096	0.0643	0.0477	0.0262	0.0041	0.1519	0.9225	1918
57	South.....	23,412	0.325	0.152	0.001	0.104	0.582	......	0.008	0.003	......	......	0.011	0.593	1923
58	East......	27,895	0.5101	0.1428	0.0049	0.0134	0.6712	0.0105	0.0524	0.0073	0.0267	0.0255	0.1224	0.7936	1904
59	Central...	33,690	0.6380	0.1788	0.0159	0.0169	0.8496	0.0034	0.0852	0.0070	0.0076	0.0044	0.1076	0.9572	1907
60	Central...	33,164	0.6057	0.1279	0.0288	0.0128	0.7752	......	0.0728	0.0203	0.0047	0.0018	0.0996	0.8752	1909
61	Central...	29,164	0.6361	0.1509	0.0190	0.0070	0.8130	0.0044	0.0253	0.0104	0.0031	0.0067	0.0499	0.8629	1917
62	East......	......	0.5748	0.2002	0.0307	0.2780[r]	1.0837	0.0273	0.0364	0.0851	0.0149	0.0005	0.1642	1.2479	1904
63	East......	27,142	0.6360	0.1370	0.0011	0.0091	0.7832	0.0093	0.0325	0.0309[f]	......	0.0021	0.0748	0.858	1908
64	East......	29,057	0.667	0.189	0.062	......	0.918	0.005	0.024	0.014	0.017	......	0.060	0.978	1916
65	East......	34,222	0.7710	0.2500	0.0163	0.0239	1.0612	0.0072	0.1457	0.0278	0.0178	0.0060	0.2045	1.2657	1907
66	West.....	26,177	0.3317	0.1223	0.0184	......	0.4724	0.0012	0.1086	0.0264	0.0227	0.0217	0.1806	0.6530	1906
67	East......	37,524	0.7650	0.2127	0.0267	......	1.0044	0.0335	0.0852	0.0198	0.0186	0.0016	0.1587	1.1631	1915
68	Central...	38,160	0.562	0.346	0.048[j]	......	0.956	0.079[k]	......	0.063[l]	......	......	0.142	1.098	1915
69	East......	20,673	0.3387	0.0620[e]	......	......	0.4007	......	......	......	......	......	0.0258	0.4265	1923
70	East......	31,175	0.6300	0.2044	0.0448	......	0.8792	0.0098	0.0793	0.0340	0.0191	0.0081	0.1503	1.0295	1917
71	East......	34,300	0.8895	0.3605	0.0170	......	1.2676	0.0044	0.2335	0.1300[f]	......	0.0108	0.3787	1.6457	1914
72	West.....	24,000	0.3358	0.0822	0.0151	......	0.4431	0.0074	0.0629[i]	......	......	......	0.0703	0.5034	1916
73	South.....	28,512	0.403	0.180	0.004	0.100	0.687	0.002	0.022	0.002	......	......	0.026	0.713	1924
74	Central[u]..	35,700	1.020	0.160	0.063	......	1.243	0.003[k]	......	0.113	0.009	......	0.125	1.368[v]	1900
75	South.....	27,860	0.4948	0.1137	0.0091	0.0047	0.6223	0.0011	0.0284	......	0.0349	......	0.0644	0.6867	1912
76	East......	29,672	0.8530	0.2605	0.0226	0.0090	1.1451	0.0448	0.0468	0.0185	0.0071	0.0533	0.1705	1.3156	1905
77	Central...	......	0.3543	0.1542	0.0333	......	0.548	0.0265	0.0721	0.0057	0.0206	0.0226	0.1475	0.6893	
78	Central...	42,266	0.7555	0.2893	0.0137	0.0045	1.0630	0.0159	0.0705	0.0120	0.0131	0.0027	0.1142	1.1772	1906
79	Central...	33,200	0.568	0.090	0.014	......	0.672	0.003	0.042	0.021	0.003	......	0.069	0.741	1918

TABLE XVII.—OPERATION COSTS, MAINTENANCE COSTS AND PERFORMANCE DATA ON AMERICAN COAL-BURNING STATIONS.[1]—(*Continued*)

Number of plant	Section of country in which plant is located	B.t.u. per net kilowatt-hour	Detail operating expenses, cents					Detail maintenance expenses, cents						Total operating and maintenance expense, cents	Date of initial operation
			Fuel	Wages and superintendence	Water lubrication and supplies	Miscellaneous	Total	Building and structures	Boiler plant	Prime movers and auxiliaries	Generators and electric equipment	Miscellaneous	Total		
80	South	35,660	0.684	0.202	0.031	0.056	0.973	0.006[k]	......	0.111	0.015	0.001	0.133	1.106	1912
81	South	34,580	0.5305	0.0897	0.0066	0.0402	0.6670	0.0074	0.0478	0.0117	0.0017	0.0361	0.1320	0.7990	1913
82	Central	26,940	0.252	0.155	0.016	......	0.423	0.008	0.017	0.009	0.001	......	0.035	0.458	1914
83	Central	42,000	0.6793	0.2082	0.0189	0.0093	0.9157	0.0215	0.0655	0.0080	0.0338	......	0.1288	1.0445	
84	South	31,238	0.5575	0.1779	0.0391	0.0181	0.7926	0.0214	0.0719	0.0316	0.0083	0.0107	0.1387	0.9313	1906
85	Central[z]	55,600	1.1885	0.1958	0.0758	0.0070	1.4671	0.0185	0.1189[w]	......	0.0680	......	0.2054	1.6725[x]	1909
86	East	......	1.011	0.382	0.030	0.053	1.473	......	......	......	......	......	......	1.4730[y]	1908
87	West	28,779	0.4900	0.0942	0.0285	0.0125	0.6252	0.0033	0.0526	0.0302	0.0138	0.0052	0.1051	0.7303	
88	West	42,000	......	......	......	......	......	......	......	......	......	......	......	1.4350	1915
89	South	32,650	0.5670	0.3408	0.1377	......	1.0455	0.0934	0.1615	0.1586	0.0095	0.0203	0.4433	1.4888	
90	Central	42,150	0.91	0.28	0.06	......	1.25	0.008	0.18	0.052	0.013	......	0.253	1.503	1910
91	Central	31,920	0.69	0.28	0.02	0.01	1.00	0.04	0.13	......	0.03	......	0.20	1.20	1912
92	East	37,565	0.6740	0.1359	0.0627	0.0057	0.8783	0.0117	0.0593	0.0128	0.0279	......	0.1117	0.9900	1910
93	East	32,170	0.5620	0.1284	0.0058	0.0019	0.7081	0.0264	0.0550	0.0666	0.0123	0.0194	0.1797	0.8878	1916
94	Central	[illegible],000	0.3870	......	......	......	......	......	......	......	......	......	......	1.3320	1908
95	Central	34,593	0.792	0.110	0.014	0.004	0.920	0.005	0.048	0.003	0.002	0.008	0.066	0.986	1913
96	Central[z]	34,600	0.769	0.292	0.019	0.012	1.092	0.0162	0.0507	0.0085	0.0095	0.0022	0.0871	1.1791	1900
97	South[d']	......	3.4950	0.9820	0.3700	......	4.8470	0.0975	0.3692	0.0675	0.0166	0.0296	0.5804	5.4274[a']	
98	Central	30,700	0.765	0.060	0.014	......	0.839	0.001	......	0.028[f]	......	0.002	0.031	0.870	
99	East	36,288	0.6240	0.2014	0.0209	0.0463	0.8926	0.0313	0.0886	0.0257	0.0217	0.0095	0.1768	1.0694	1918
100	East	......	0.80	0.48	0.06	......	1.34	0.03	0.08	0.04[f]	......	......	0.15	1.49	1907
101	West	42,500	0.7530	0.2720	0.0641	......	1.0891	0.0100	0.0953	0.0220	0.0048	......	0.1321	1.2212	
102	Central	36,600	0.7236	0.3408	0.0388	......	1.1032	0.0239	0.0367	0.0077	0.0017	......	0.0700	1.1732	1906
103	West	37,886	0.4898	0.1885	0.0146	0.0185	[illegible]	0.0022	0.0746	0.0354	0.0159	0.0013	0.1294	0.8408	
104	Central	25,545	0.6583	0.1720[c']	......	......	0.8303	......	......	......	......	......	0.2597	1.1900	1921
105	Central	48,431	0.8395	0.2628	0.0212	0.0506	1.1741	0.0003	0.0049	0.0014	0.0016	0.0003	0.0085	1.1826	1908
106	Central	45,800	0.7734	0.4293	0.0557	0.0117	1.2701	0.0029	0.0626[i]	......	......	......	0.0655	1.3356	1903
107	South	36,250	1.108	0.2713	0.0736	......	1.4529	......	......	......	......	......	0.3420	1.7949	1911
108	East	59,400	0.9650	0.3682	0.0540	......	1.3872	0.0030	0.0710[l]	......	0.0168	0.0001	0.0909	1.4781	
109	East	......	0.9950	0.6185	0.0351	0.0288	1.6774	0.0427	0.0930	0.0362	0.1509	0.0063	0.3291	2.0065	1914
110	East	31,500	0.5505	0.6522	0.0215	......	1.2232	0.0211	0.0076	0.0196	0.0065	0.0039	0.0587	1.2819	1905
111	South	54,700	0.960	0.364	0.063	0.012	1.399	0.022	0.095	0.065	0.088	0.010	0.280	1.679	1911
112	East	60,661	1.2150	0.4115	0.0708	0.0108	1.7081	0.0770	0.1777	0.0610	0.0175	0.0255	0.3587	2.0668	1900

113	West	47,081	0.4850	0.2312	0.0123	0.0452	0.7737	0.0087	0.0666	0.0807	0.0103	0.0106	0.1829	0.9566	1910
114	East	69,984	1.2910	0.5055	0.0438	......	1.8433	0.0248	0.0876	0.0135	0.0414	......	0.1673	2.0106	1904
115	Central	49,000	1.1568	0.2927	0.0231	0.0084	1.4810	0.0029	0.0411	0.0184	0.0124	0.0010	0.0758	1.5568	1907
116	Central	34,928	0.5935	0.2635	0.0494	0.0137	0.9201	0.0137	0.2745	0.0330	....	0.0137	0.3349	1.2550	1916
117	Central	34,359	0.6900	0.5015	0.0301	......	1.200	0.004	0.090	0.004	0.003	0.005	0.106	1.306	1916
118	Central	......	0.3816	0.2995	0.0480	0.0131	0.7422	0.0207	0.0248	0.0315	0.0407	0.0011	0.1188	0.8610	
119	South[d']	80,000	1.6800	0.8954	0.0615	0.2327	2.8696	0.0432	......	......	0.1650	......	0.2080	3.0778	1910
120	Central	......	......	......	......	......	......	......	......	......	......	......	......	4.55	1907
121	Central	54,492	1.20	0.22	0.03	......	1.45	0.01	0.15	......	0.01	......	0.17	1.62	1920
122	South	78,480	1.3670	0.5250	0.0481	......	1.9401	0.0066	0.0184	0.0273	0.0119	0.0681	0.1323	2.0724	1912
123	Central	......	1.1750	0.9317	0.1741	0.3477	2.6285	0.0261	0.5520	0.2260	......	0.0690	0.8731	3.5016	1922
124	East	48,552	1.09	0.61	0.04	......	1.74	0.006	0.121	0.008	0.027	......	0.162	1.902	1916
125	West	58,630	0.605	0.266	0.083	......	0.954	0.009	0.071	0.047	0.018	......	0.145	1.099	1907
126	West	70,735	1.4065	0.7520	0.1336	0.0970	2.3891	0.0474	0.0694	0.0428	0.0138	0.0200	0.1934	2.5825	1905
127	West	62,010	1.8440	0.6455	0.0232	......	2.5127	......	......	......	......	......	0.2947	2.8074	1910
128	West	70,365	1.1300	0.7863	0.0944	0.0528	2.0635	0.0055	0.4495	0.0489	0.0052	0.0226	0.5317	2.5952	
129	West	68,300	1.715	1.156	0.052	0.090	3.013	0.077	0.262	0.139	0.009	......	0.437	3.523	1912
130	Central	105,395	1.1000	1.0850	0.1384	0.7585	3.0819	0.1588	0.1940	0.0190	0.1198	0.0324	0.5240	3.6059	1912
131	Central	126,500	1.8940	1.4000	......	......	3.2940	......	......	......	......	......	0.3060	3.6000	1922
132	West	......	2.4150	1.1960	0.2182	0.1103	3.9395	0.0314	0.0995	......	......	......	0.1309	4.1704	1921
133	Central	56,800	......	......	......	......	......	......	......	......	......	......	......	3.0625	1912
134	Central	112,000	1.3790	1.6720	0.2690	0.0241	3.3441	0.0258	0.0086	0.1207	0.0103	0.0069	0.1723	3.5264	1917
135	South	140,000	3.0800	1.0270	0.3372	0.1653	4.6095	......	......	......	......	......	0.4407	5.0502	1904
136	Central	130,000	3.7600	1.4830	0.6205	0.0056	5.8691	......	......	......	......	......	0.5450	6.4141	1914

[1] *Electrical World*, Sept. 26, 1925.

[a] Operated in system having hydro-electric plants.

[b] Four-month period.

[c] Five-month period.

[d] 30,000-kw. unit in commission Sept. 19, 1924.

[e] 30,000-kw. unit in commission Nov. 30, 1924.

[f] Includes generators and electrical equipment.

[g] Two-thirds of capacity added during 1924.

[h] Natural gas used part of time; figure given is coal and gas equivalent in erms of coal.

[i] Includes prime movers, auxiliaries, generators and electrical equipment.

[j] Includes miscellaneous.

[k] Includes boiler plant.

[l] Includes generators, electrical equipment and miscellaneous.

[m] Standby to newer steam plant.

[n] Includes some purchased energy, expenses based on energy generated only.

[o] With additional 35,000-kw. unit this plant over a month's period operated at load factor of 58 per cent, 17,200 B.t.u. per kilowatt-hour, and total operating (0.402) and maintenance (0.017) expense of 0.419 cts.

[p] Used 6,985 bbl. oil, also included in expenses.

[q] Used 38,919 bbl. oil at 143,099 B.t.u. per gallon.

[r] Current purchased and miscellaneous expenses.

[s] Includes water, lubrication, supplies and miscellaneous.

[t] In operation Aug. 1, 1924.

[u] Two plants combined.

[v] Includes steam heating system cost prorated at 0.165 ct. per kilowatt-hour.

[w] Includes prime movers and auxiliaries.

[x] Includes 86,324,000 lb. of steam heat; 429,200 kw.-hr. was generated by three small Diesel engines, the fuel expenses of which are not included.

[y] Includes maintenance.

[z] Includes separate station of 1,000 kw. seldom used.

[a'] Steam heating system included.

[b'] 81 per cent of energy generated with wood refuse.

[c'] Includes water, lubrication and supplies.

[d'] Reciprocating engine replaced by turbo-generator Nov. 7, 1924.

[e'] Annual plant use factor $= \dfrac{\text{Net kilowatt-hour}}{\text{Kilowatt installed} \times 8{,}760}$

[f'] Annual load factor $= \dfrac{\text{Net kilowatt-hour}}{\text{Peak load (kilowatt)} \times 8{,}760}$

CHAPTER VI

AUXILIARY ENERGY SUPPLY AND HEAT-BALANCE SYSTEMS

The trend in modern stations is to make unit power plants inside of the main station structure. A boiler or boilers with its turbo-generator and auxiliaries forms an operating unit and the degree to which any part of the unit plant assembly is interlocked or connected with parts of other units is determined by a study of operating economy and reliability.

A large unit plant represents a great investment and a large proportion of the capacity of the power station. It is essential, therefore, that this unit plant be equipped with auxiliaries which can be relied upon and which will function properly under all conditions of operation. A dollar saved on an essential auxiliary device by decreasing its reliability is false economy when the failure of this device prevents a very large investment from earning a return.

The choice of a system of auxiliaries and the selection of a method for making auxiliaries reliable are associated with the application of the heat recirculation principle to increase the thermal efficiency of the station. Exhaust steam from steam-driven auxiliaries, heated air from generators and the most economical method of using steam to get an energy supply for auxiliaries are factors to be considered from the thermal-efficiency standpoint as well as from the standpoint of an economical and reliable auxiliary installation.

Then again a power station which is interconnected with other stations can rely upon an energy supply for auxiliaries from the other stations in case of emergency, but a single station must be able to start up and operate as a self-contained unit. Thus, any particular station has local features which weigh heavily in deciding upon an auxiliary system and a heat-balance system.

Most power stations rely upon electric drives for all auxiliaries under normal operating conditions. These electric drives may be supplemented by steam-driven installations for emergency use.

In a somewhat analogous manner, the energy supply for electric drives on auxiliaries is usually secured from the main generators

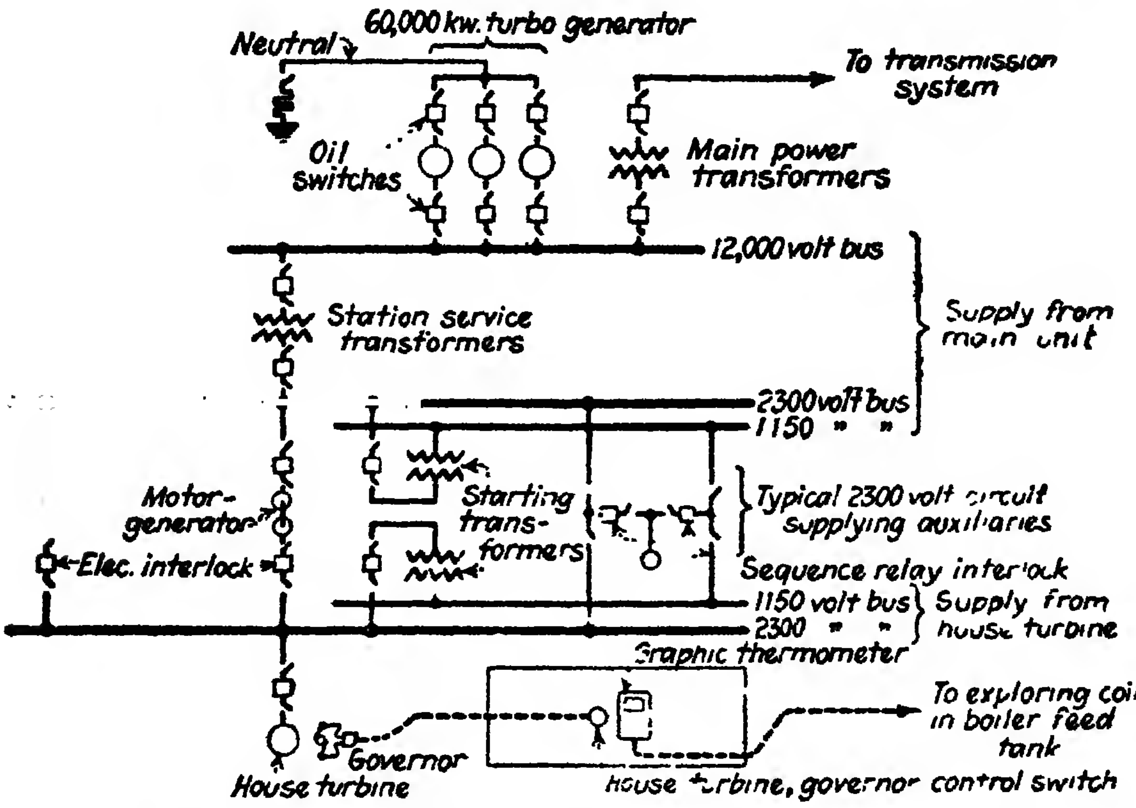

FIG. 50.—Auxiliary service in the Colfax station of the Duquesne Light Company. House turbo-generator, 1-2,000-kw., 2,300-volt, three-phase, sixty-cycle. Motor-generator heat-balance set, 1 1,100-hp., 2,300-volt, wound-rotor motor driving 750-kw., three-phase, 2,300-volt generator. Duplex exciter sets, two sets each having a 250-volt, 350 kw., direct-current generator, a 530-hp. 2,300-volt motor and a turbine. All are mounted on one shaft.

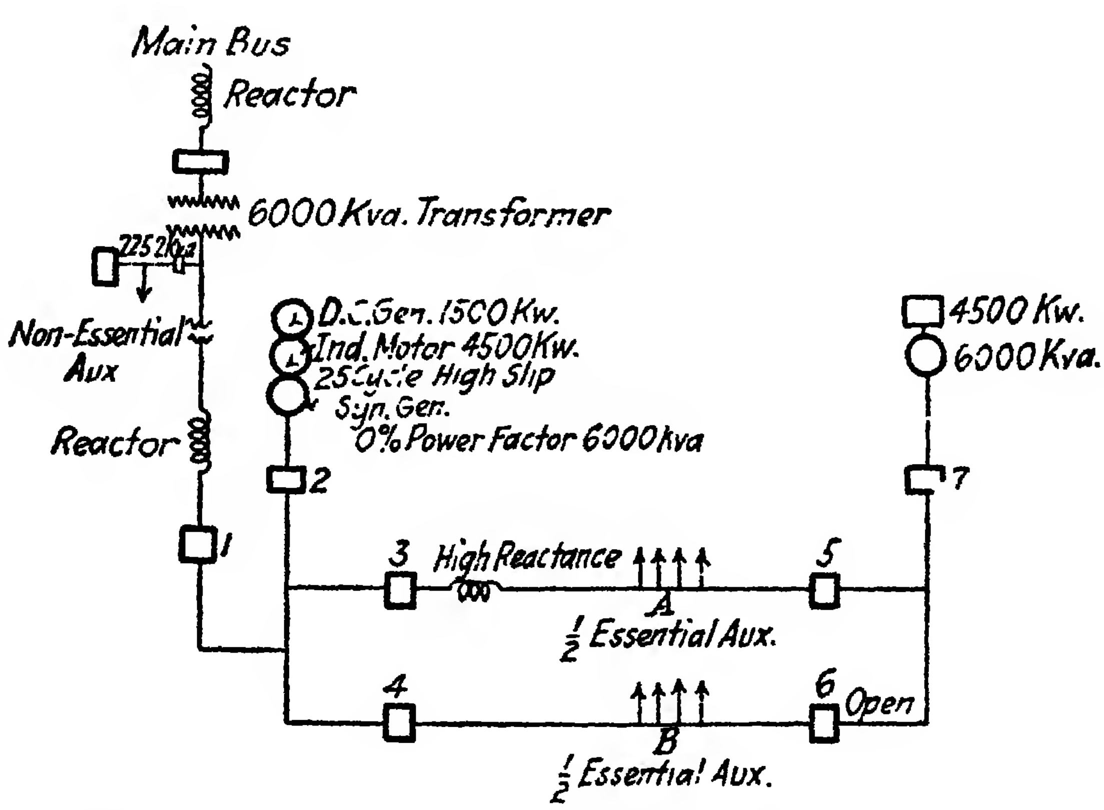

FIG. 51.—Auxiliary power supply for the Hudson Avenue station of the Brooklyn Edison Company.

or from auxiliary generators on the same shaft as the main generators or from a supplementary or emergency supply from a reserve unit called a house turbo-generator.

TABLE XVIII.—PERFORMANCE OF TWELVE MODERNLY EQUIPPED STEAM POWER PLANTS[1]

Plant	Period covered	Installed generator capacity, main units, kilowatts, December, 1925	Date put in operation	Total kilowatt-hours, generated by main units	Net kilowatt-hours generated	Peak load, kilowatt	Plant use factor, per cent	Plant load factor, per cent	Fuel consumption, short tons
A	1925	[illegible],000 (7/31/24) 50,000 (3/18/24) 50,000 (1/12/25)	July 31, 1924	537,185,800	507,230,800	128,000	41.3	45.2[k]	305,086
	Dec., 1925	150,000 (see above)	July 31, 1924		55,600,800	128,000	49.8	58.4	32.551
B	1925	80,000	Sept 25, 1924	342,619,000	324,515,000	78,000	51.0	62	220.684
	Dec., 1925	80,000	Sept 25, 1924	37,869,000	36,055,900	70,000	63.6	73	23.842
C[a]	Apr. 6–9, 1926	90,000	Dec 10, 1925	3,131,900	2,931,200	36,000	36.3	90.6	1,385.25
D	Dec., 1925	288,000	Original in Sept. 1, 1911	93,328,000	91,145,050	216,000	43.5	62.44	72,659
E[f]	Dec., 1925	145,000	Oct 17, 1923	50,504,000	47,758,100	125,050	46.8[b]	54.2	37,679
F	Dec., 1925	20,000	Dec. 1, 1924	12,184,000	11,626,300	23,000 (hourly)	81.8	71.2	11,245
G[c]	June 2, 1925, to Jan. 1, 1926	35,000[c]	June 2, 1925	42,902,100	40,766,752	35,000	27.5	23.9	537,423,000 cu. ft. (natural gas) 6,618,741 bbl. of 42 gal. each (oil)
H[d]	Jan., 1926	85,000[d]	Nov. 29, 1924	58,462,100	56,669,480	88,200[d]	92.5[d]	89.2[d]	232,489,000 cu ft. gas; 92,718 bbl. oil
I[e]	Feb., 1926	32,000	Nov. 1, 1925	10,240,204	9,879,670	33,500	49	43.9	Oil 8,545,000 lb
J[f]	Dec., 1925	Three 22,500	Apr 18, 1924	16,670,000[c]	15,970,500	46,700	33.2	48	11,360
K[g]	Dec., 1925	122,000	Orig 1904; Pulv fuel Mar., 1925	14,031,400	13,262,140	18,000	15.16	39.3	18,074 for power generation, 15,326 for steam heating[g]
L[h]	Mar., 1926	2—30,000 kw. 1—[illegible],150 kw.	Jan. 17, 1925	21,561,000	21,143,629	34,325	45.9	84.4	10,931.86

[1] *Electrical World*, May 8, 1926.
[a] Reheating not in use at present
[b] 763,000 kw.-hr. of total reported was generated by house turbines, the 4,000-kw. capacity of which was not included in plant capacity of 145,000 kw.
[c] Net normal generator rating at 85 per cent power factor is 30,000 kw. and maximum net rating at 85 per cent power factor is 35,000 kw.
[d] The name-plate ratings on the generators totals 75,600 kw., considering this and the peak load of 88,200, the plant use factor is higher than the plant load factor. The ratio of gross kilowatt-hours to the product of name-plate rating and turbine hours is 107.99 per cent.
[e] Station I did not operate over week-ends; B.t.us. per net kilowatt-hour during generating period of 506 hr. were 14,760; station service during generating period was 337,460 kw.-hr., and load factor 60.3 per cent. Total generated power includes (360,534) generated by 2,000-kw. auxiliary generator. Also 532,600 lb. of oil was used in standby service.

TABLE XVIII.—PERFORMANCE OF TWELVE MODERNLY EQUIPPED STEAM POWER PLANTS.[1]—(*Continued*)

Plant	Average B.t.u. per pound fired	Average per cent ash	Fuel cost per short ton delivered	Fuel cost per million B.t.u.	B.t.u. per net kilowatt-hour	Steam pressure at throttle, pounds	Steam temperature, degrees Fahrenheit	Powdered fuel	Stokers	Reheating of steam	Number of bleeding points	Economizers	Air preheating
A	13,660	7 2	$4 06	$0.1487	16,432	380	695	Yes	No	No	3	Yes	
	13,520	7 2	$4 07	$0.150	15,830	380	695	Yes	No	No	3	Yes	
B	10,768	12.77	$2.15	$0.114	14,707	530	706	No	Yes	Yes	2	Yes	Half of furnace so equipped
	10,796	11.56	$2.17	$0 10	14,251	530	706	No	Yes	Yes	2	Yes	Half of furnace so equipped
C[a]	14,170	7 05	. .	. . . . .	13,390	545	720	Yes	No	Yes[a]	3	Yes	Yes
D	12,764 (dry)	14.1	. . .	. . . . . .	19,190	225 and 250	530 and 675	Yes	Yes	No	1	Yes	
E[f]	10,830	13 (11 per cent moisture)	$3.09	$0.143	17,100	304	700	Yes	No	No	3	No	Two of the latest furnaces so equipped but not in operation during Dec.
F	9,436 (lignite)	4 5	$1 80	$0 095	18,253	369 (av.)	623 (av.)	Yes	No	No	3		Yes
G[e]	1,235 B.t.u. per cu. ft. 18,935 B.t.u. per lb.	. . . .	Gas $0 20 per M ft Oil $1 20 per bbl.	$0.16 for gas, $0.15 for oil	16,250	370 (av.)	695 (av.)	No	Natural Gas and oil	No	4	. . . .	Yes
H[d]	1,134 B.t.u. per cu. ft. (gas) 18,600 for oil	. . . . . .	. . . .	. . . . .	14,933	375	700	No	Gas and oil	No	3	Yes	No
I[e]	18,200	. . . .	$1 75 per bbl	$0.286	15.720[c]	350	700	No	Oil				
J[f]	13,750	9.74	$5 67	$0 206	19,600	310	603	No	Yes[f]				
K[g]	10,778	13 4	$3 32	$0 153	29,377	190	513	Yes	Yes	No	No	Yes	No
L[h]	14,065	6 60; S = 1.13 Moist = 3 94	$5.04 in bunkers	$0.179	14,330	350[h] and 1,200	700	. . . .	Yes[h]				

[f] Station J operates in conjunction with two hydro plants of 25,900-kw. capacity. Due to this, the load factor of Station J was only 48 per cent. although the system load factory was 54.8 per cent. For auxiliaries, 699,500 kw.-hr. were used. All auxiliaries except boiler feed pumps are motor driven. Stokers developed 258 per cent of nominal boiler rating continuously, and 300 per cent for 4 hr.

[g] Large portion of steam generated for district steam heating.

[h] A steam pressure of 350 lb. is used with 30,000-kw unit and 1,200 lb. with 3,150-kw. unit; the 1,200-lb outfit was not used enough to have material influence on performance; three 1,974-hp. boilers and one 1,573-hp. boiler used with stokers operated at 225 per cent rating. Auxiliary power was furnished chiefly (881,000) by two 2,000-kw. auxiliary generators on main shaft, and partly (120,371) by main units.

[i] Plant use factor = gross kilowatt-hour, generated by main units divided by (rating of main units × hours in period considered).

[j] Plant load factor = gross kilowatt-hour, generated by main units divided by (peak load × hours in the period considered).

[k] Load factor was figured on basis of net kilowatt-hour.

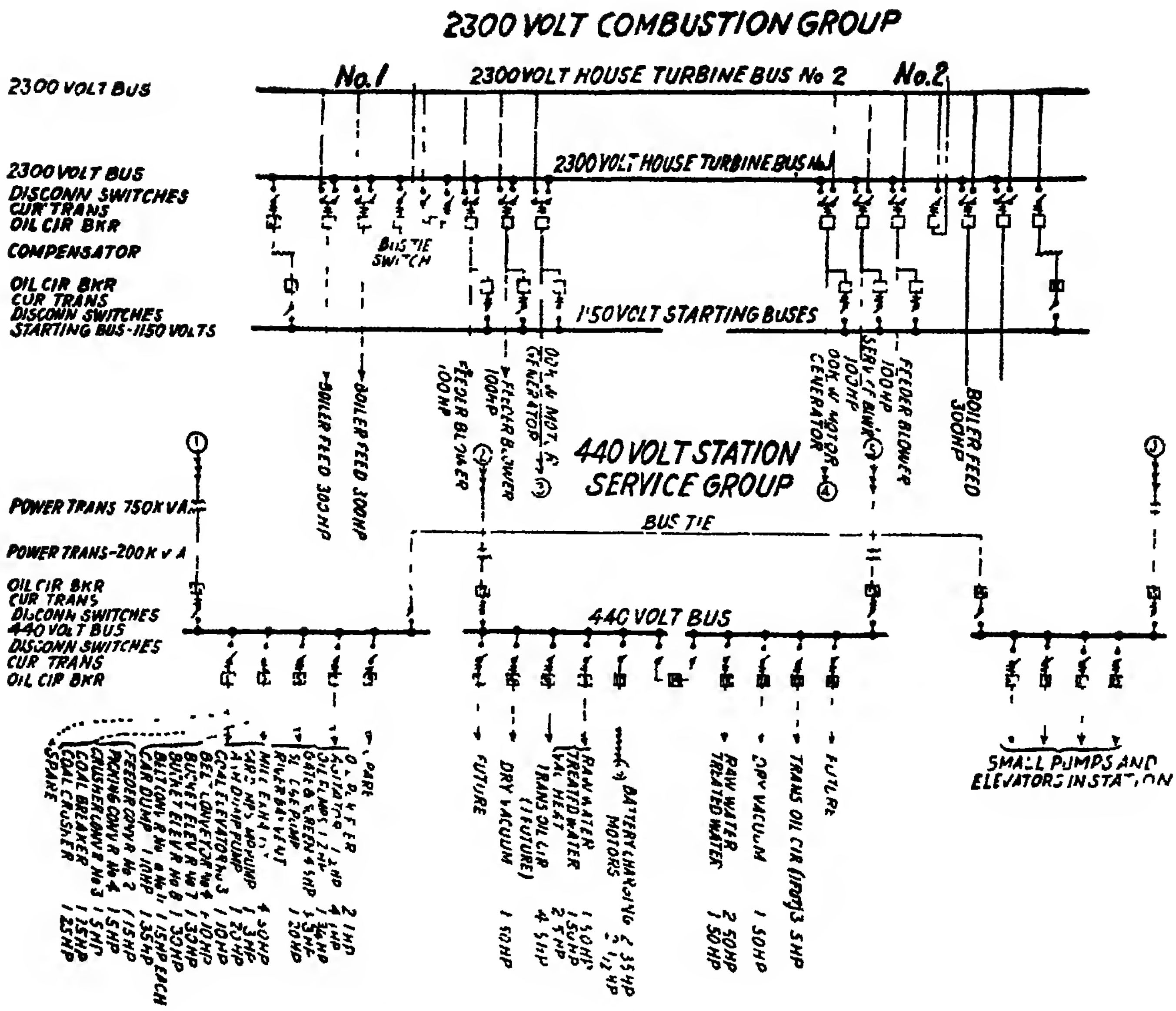

FIG. 52a.

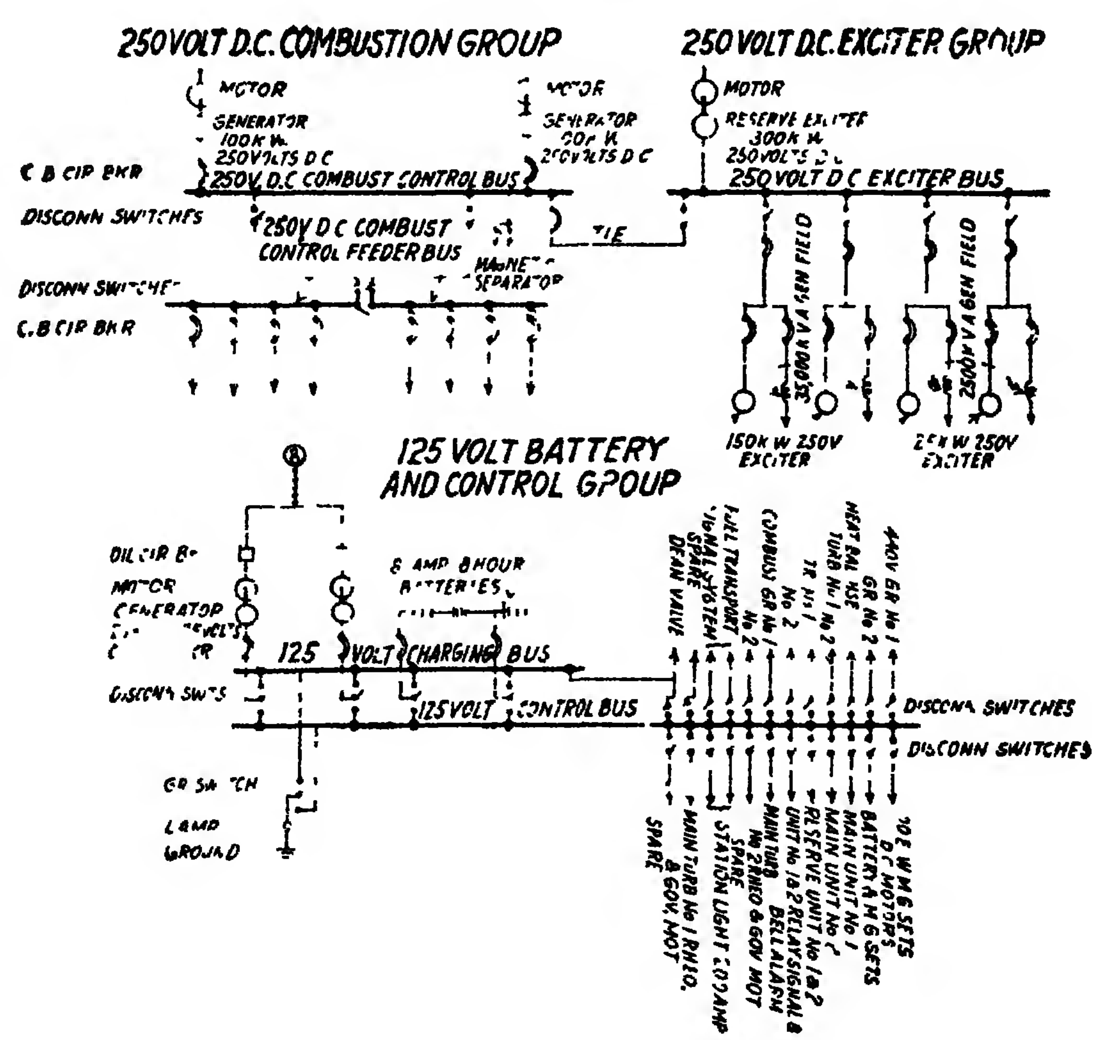

FIG. 52b.

Motor-driven auxiliaries are favored because they are generally more reliable and more economical than steam-driven auxiliaries. Piping and heat losses are eliminated, the control is simpler and more flexible for remote operation, the energy for supplying the auxiliaries can be secured more economically and more efficiently and a simpler and more efficient heat-balance system can be installed.

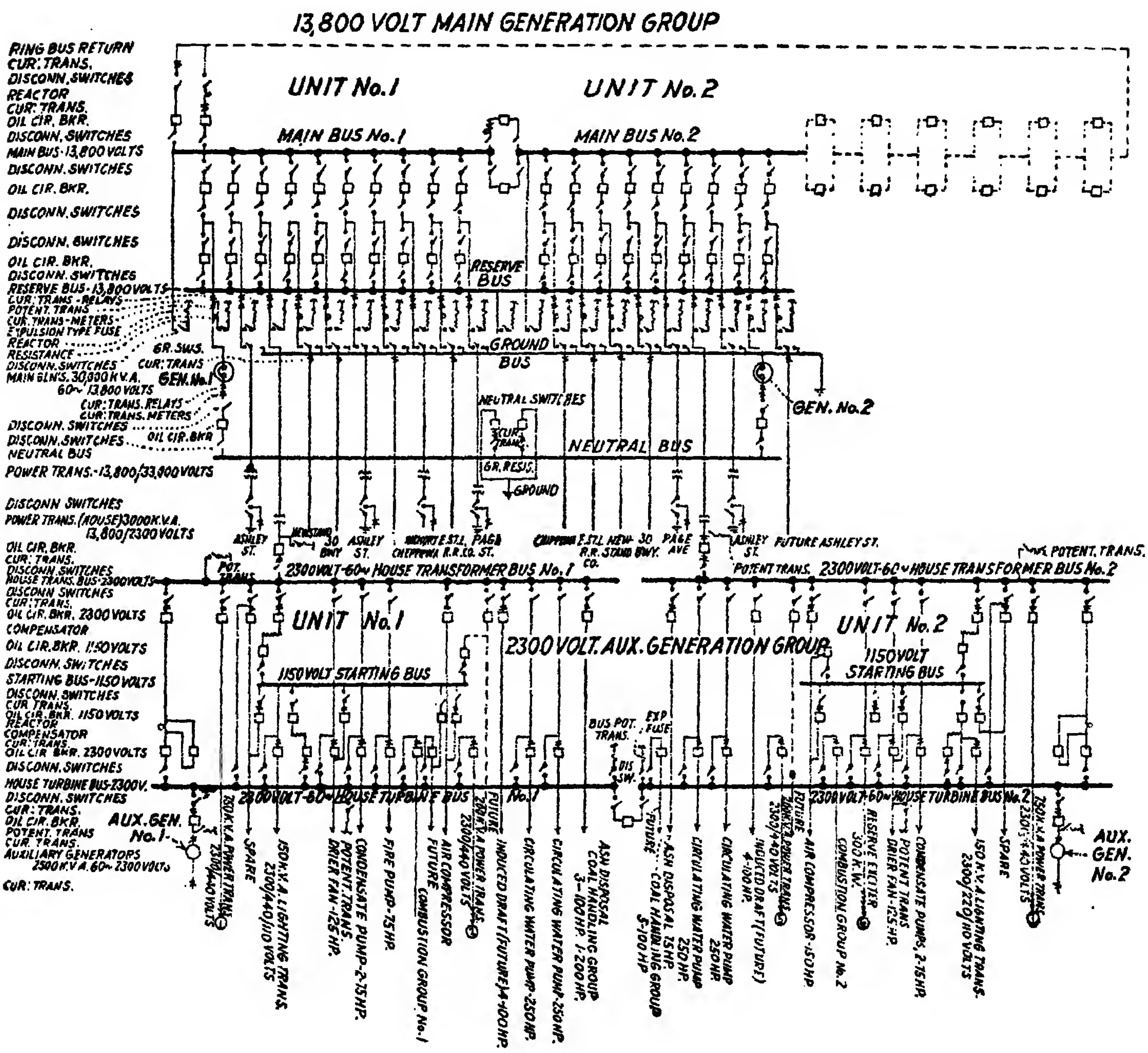

FIG. 53c.

FIG. 52a, b, and c.—Auxiliary supply for the Cahokia station of the Union Electric Light and Power Company.

Reliability of Supply.—When motor-driven auxiliaries are used it is essential to design a reliable method for supplying them with energy and to get this energy most efficiently and economically. It is also necessary to devise some means for obtaining adjustable or variable speed on the motors which drive certain auxiliaries, such as stokers or fans.

Several methods have been proposed or used to secure a reliable energy supply to auxiliaries and local conditions and designers' opinions often determine which scheme is used in a particular station.

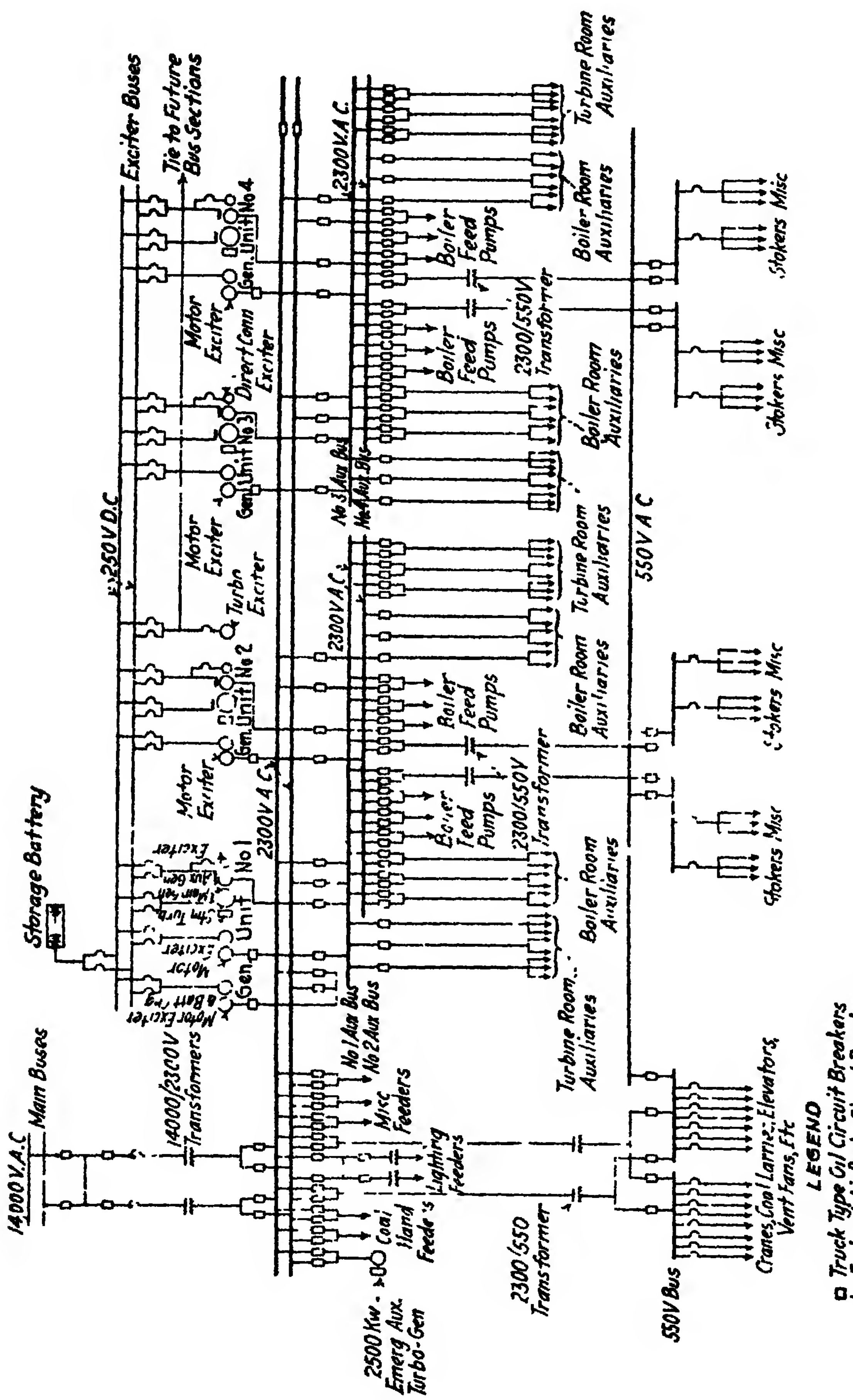

FIG. 53.—Auxiliary supply of Edgar station of the Edison Electric Illuminating Company of Boston.

1. In some very recent stations the main generator and the main step-up transformer for the generator are considered as a unit in order to avoid switching at generator voltage. In these stations a common practice is to place a transformer for supply-

ing the auxiliaries of this unit in the generator leads. This high-reactance transformer normally supplies its own unit auxiliaries, but may be connected to a reserve or emergency bus of small energy capacity in addition. This system tends to localize trouble with auxiliaries to one unit, provides a simple layout and reduces the hazards from trouble arising in other parts of the station to a minimum.

2. A house turbo-generator as a reserve or emergency supply for auxiliaries with the normal supply from the main bus through

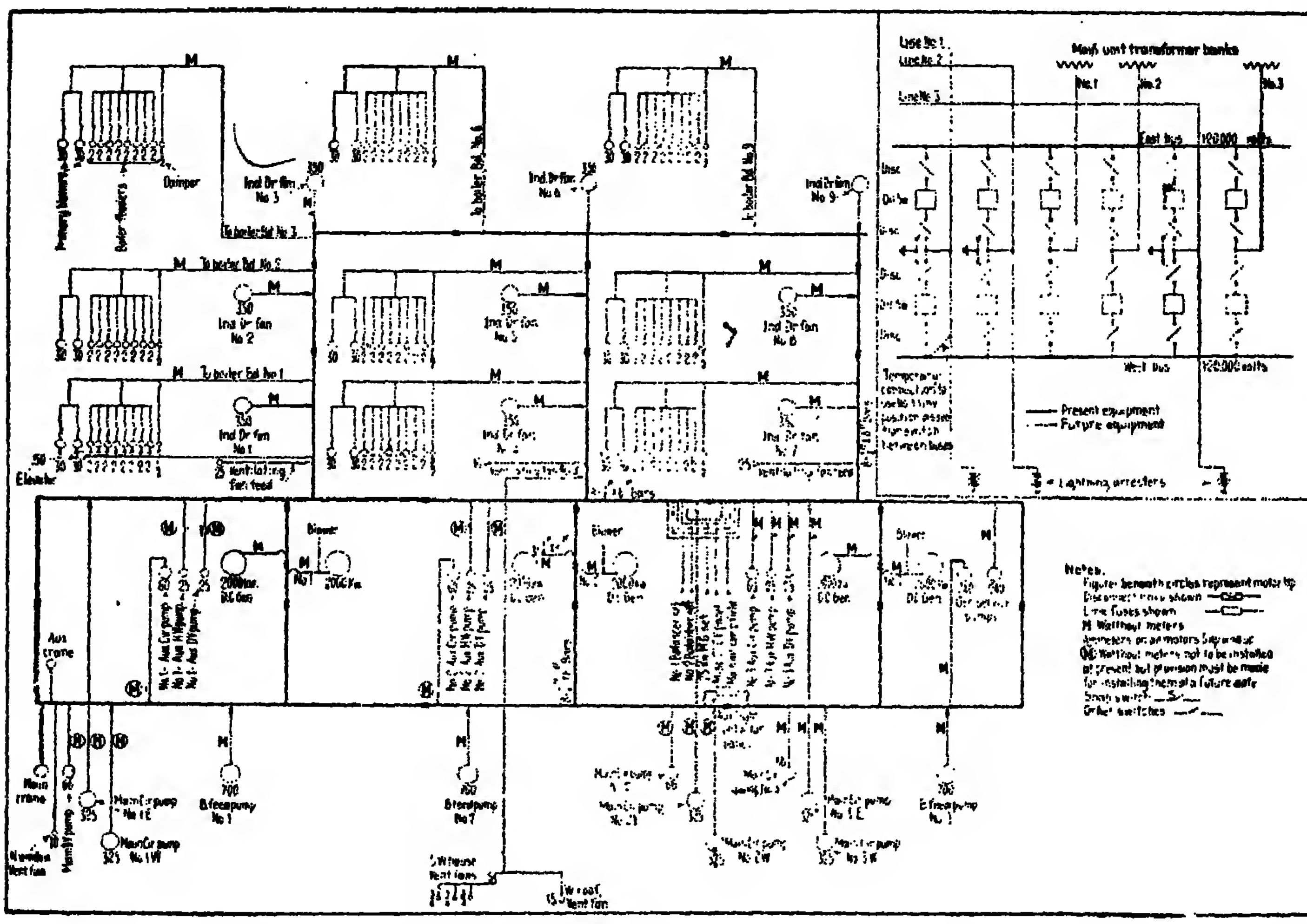

FIG. 54.—Auxiliary layout for the Trenton Channel station of the Detroit Edison Company.

a transformer is a very common scheme in many stations. It affords a reliable supply, but the layout is rather complicated. The greatest drawback to this system lies in the fact that steam extraction from the main units is found more efficient in the heat-balance system than when exhaust steam from the house turbo-generator is used.

3. A duplex drive system is installed in several stations. This involves a turbine-motor-generator unit on one shaft for supplying the auxiliaries. Under normal conditions the motor is energized from the main unit bus to drive the auxiliary generator. But under emergency conditions when there is a failure of motor energy supply the governor of the turbine acts to cause the tur-

bine to pick up the auxiliary load. This type of installation is very reliable, but does not fit efficiently in the more recent heat-balance systems using main unit steam extraction or bleeding.

4. An auxiliary generator mounted on the extended shaft of each main turbo-generator is a modern type of auxiliary supply. This generator normally supplies power for the auxiliaries of the power station assembly used with the main unit. A small steam turbo-generator equal in capacity to one or two main unit auxiliary generators with a transfer bus arrangement so that it may supply any station unit is often used as a reserve or emergency station auxiliary supply should a shaft generator fail, or for use

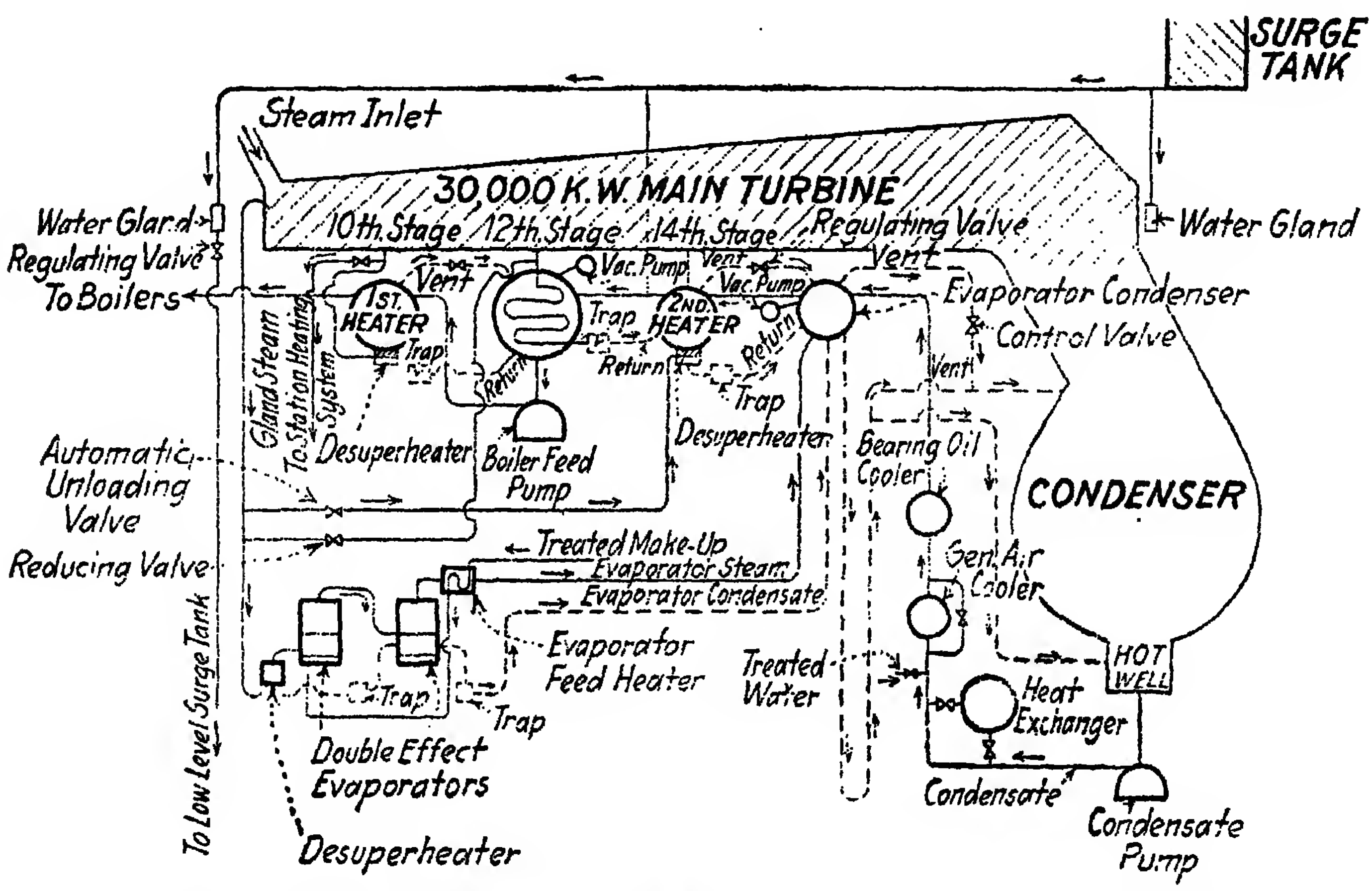

FIG. 55.—Heat-balance diagram of the Cahokia station of the Union Electric Light and Power Company.

in the station when it is started in operation. This system is economical and very efficient from a thermal standpoint because the steam in the main turbine is used to drive the auxiliaries under normal conditions.

5. Combinations of systems may be used, and the system installed in the Hudson Avenue station by the Brooklyn Edison Company shows the extent to which the designers went to insure reliable auxiliary service. Figure 51 shows the layout of the auxiliary service. The auxiliaries, which are all motor driven except one boiler feed pump (there being three to each group of two main units), are supplied from two buses, one-half being connected to *A* bus and one-half to *B* bus. These two buses are

supplied at one end by a 6,000-kva. transformer bank taking current from the main bus and an induction-motor synchronous-generator set. The synchronous generator is a 60-cycle machine of 5,000-kva. capacity and the induction motor is a 25-cycle machine of 4,500-kw. capacity. A 1,500-kw. direct-current generator for supplying current to stoker, clinker roll and forced-draft fan motors is also made a part of this set.

The opposite end of the two buses are supplied by a 4,500-kw. house turbine with a 6,000-kva. generator. This generator is good for 6,000 kva. at 0 per cent power factor. Reactances are

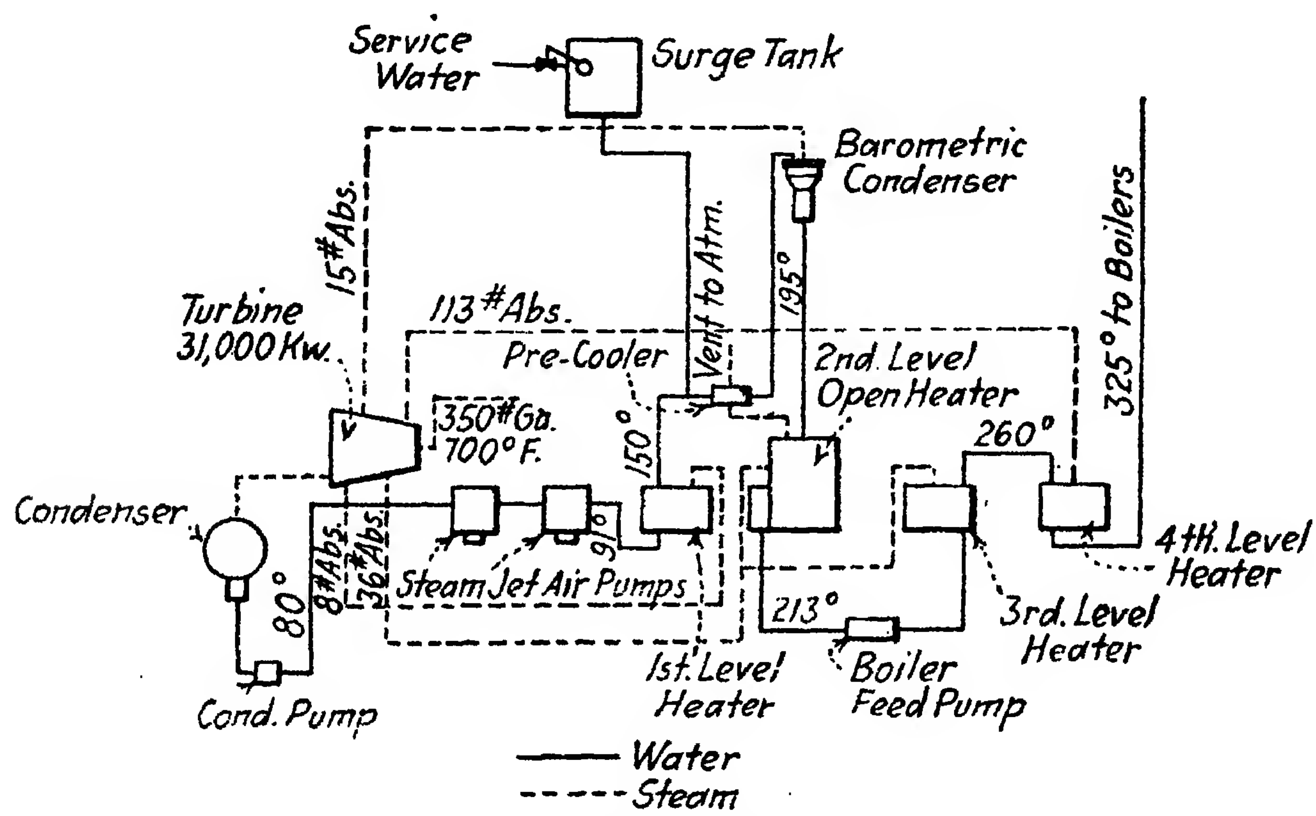

FIG. 56.—Heat-balance diagram of the Kearny station of the Public Service Electric and Gas Company.

installed before and after the transformer bank and a quite high reactance on bus A next to switch 3.

Under normal operation, swtich 6 is left open and the synchronous-induction motor-generator set is just floating on the line, taking no current from the 25-cycle system to which it is connected but with the synchronous machine running as a condenser and correcting the power factor and also driving the direct-current generator.

All sets have differential relay protection and the worst that can happen through trouble to any one of the three is loss of one-half the auxiliaries, leaving two sources of supply connected to the bus. With this arrangement it is also possible to shut down the house turbine, securing better economy and still having two separate sources of supply for the auxiliaries.

6. Combination arrangements of shaft-end generators and house turbo-generators are often used for large stations. These systems are based on dividing the auxiliaries into two groups—essential and non-essential. Circulating water pumps, boiler-feed pumps and other auxiliaries necessary at all times for main unit operation are called essential auxiliaries. Forced-draft fans, induced-draft fans and other auxiliaries which may be out of service for short periods without affecting the operation of the

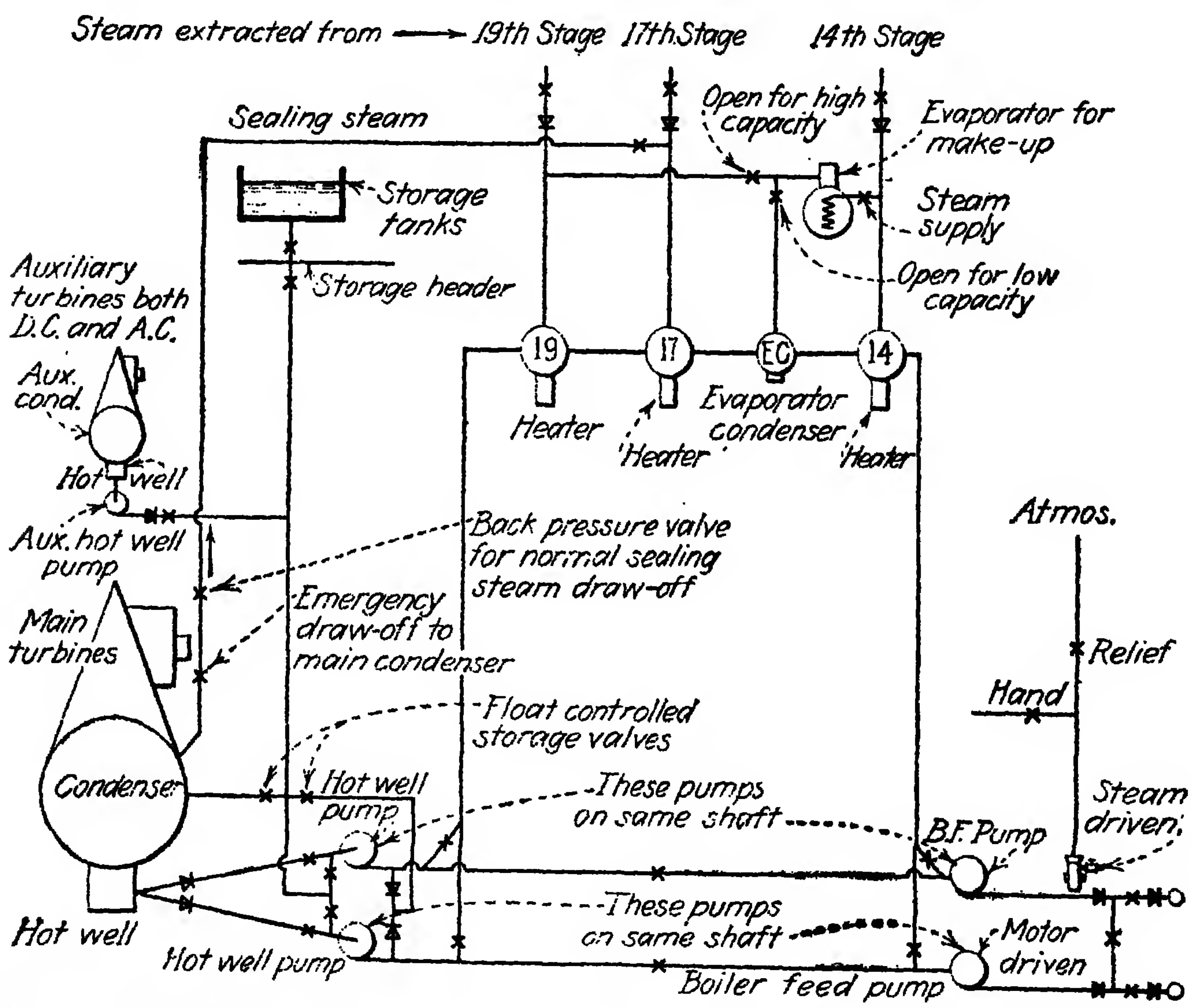

FIG. 57.—Feed-water system of Trenton Channel station of Detroit Edison Company.

main unit materially are called non-essential. Two typical arrangements for this combination are as follows:

a. A shaft-end generator on the main unit supplies the auxiliary bus used in normal operation and an automatic switch throws the auxiliaries on a reserve bus supplied by a transformer connected to the main station when trouble occurs. This is a simple and very reliable system for a station which is interconnected with other stations.

b. A modification of the foregoing installation uses a house turbo-generator to operate in parallel with the shaft-end generator auxiliary bus and with the reserve bus supplied through trans-

formers from the main bus. This house unit may be connected to carry no load under normal conditions but will operate under abnormal conditions to carry the auxiliary load for one or more

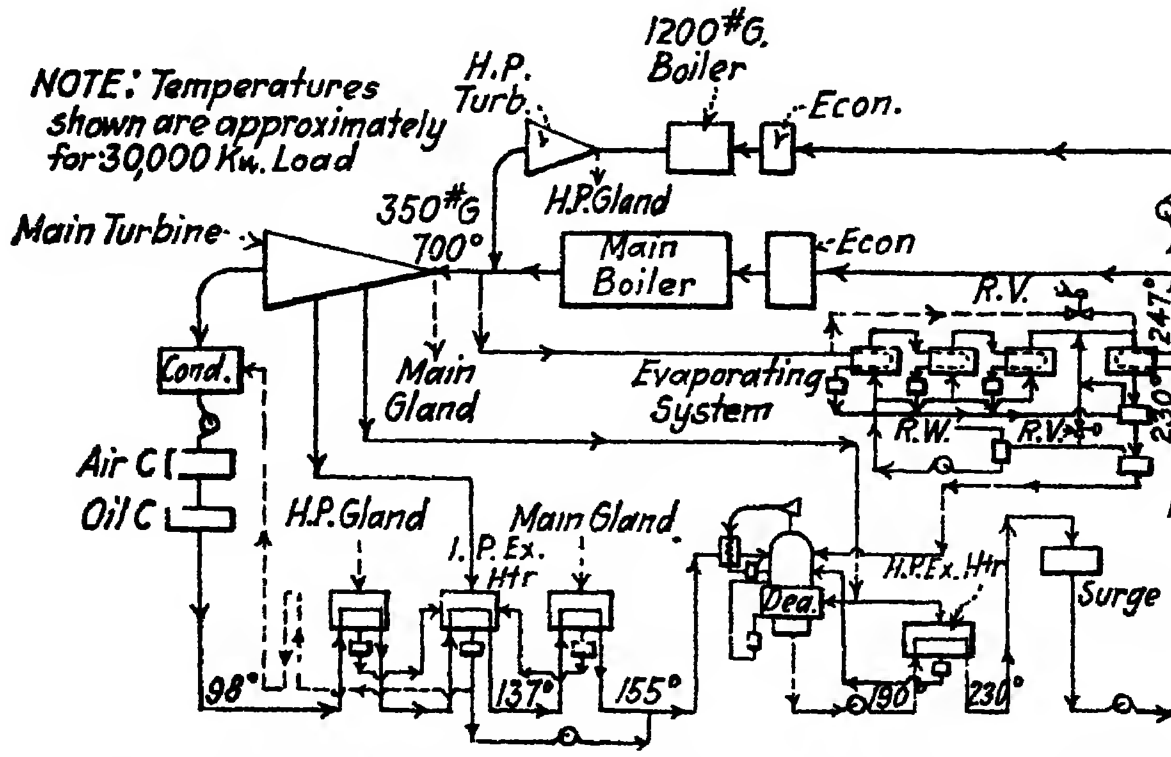

FIG. 58.—Heat-balance diagram for Edgar station of Edison Electric Illuminating Company of Boston

main units. When trouble occurs with the shaft generator supplying the auxiliary bus the load is transferred to the house

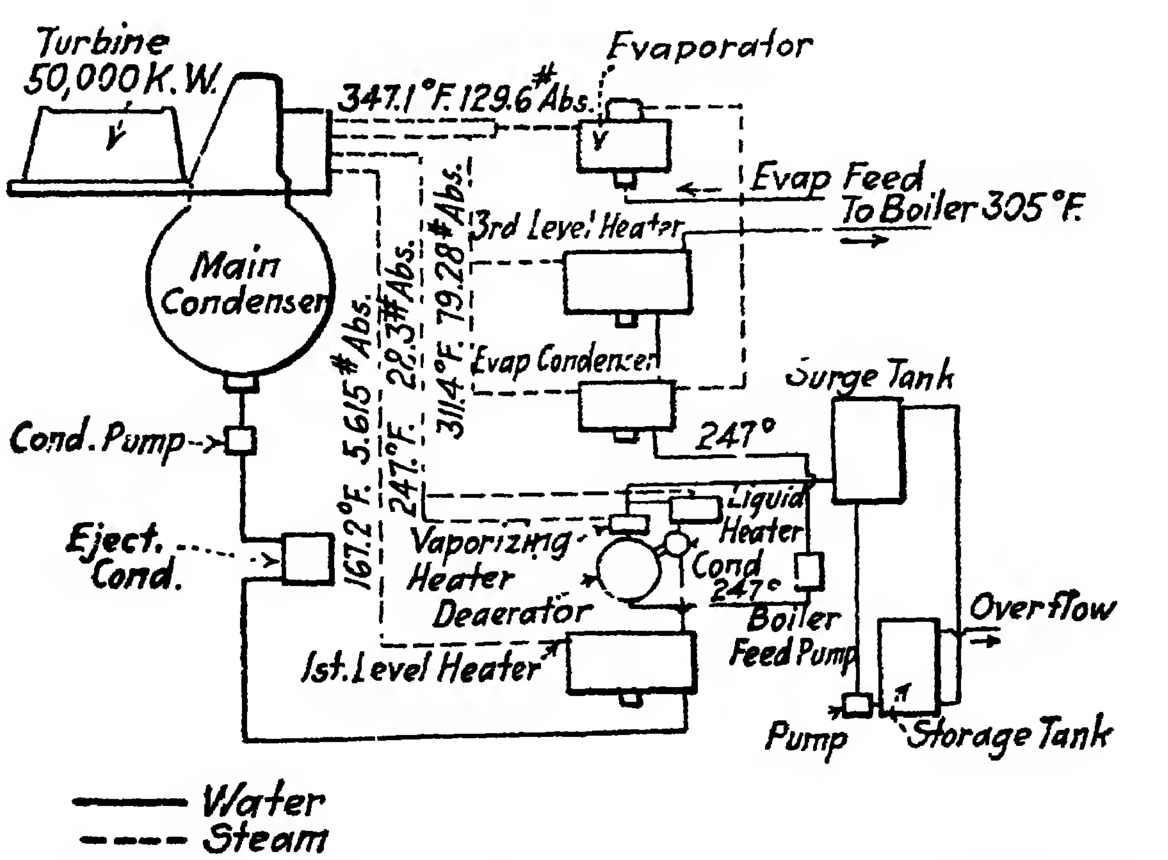

FIG. 59.—Heat-balance diagram of Richmond station of the Philadelphia Electric Company.

turbo-generator. In a similar manner, reverse energy relays can be used to disconnect the house unit from the reserve auxiliary bus in the event trouble occurs on that supply. This

system permits the use of shaft-end generators of reduced capacity and affords a means for starting the station.

The merits and demerits of the various auxiliary systems depend on opinion and local operating conditions, but some general statements apply. When two auxiliary buses are used, one supplied from the main bus and the other from a house generator, a reliable supply is obtained but it is more difficult to maintain heat balance unless main unit bleeding and main unit load shifting are practiced. And when these two buses are tied with a reactor so that parallel operation can occur, it is difficult to use a reactor which will localize trouble and yet permit auxiliary energy to be supplied through it. Heat-balance

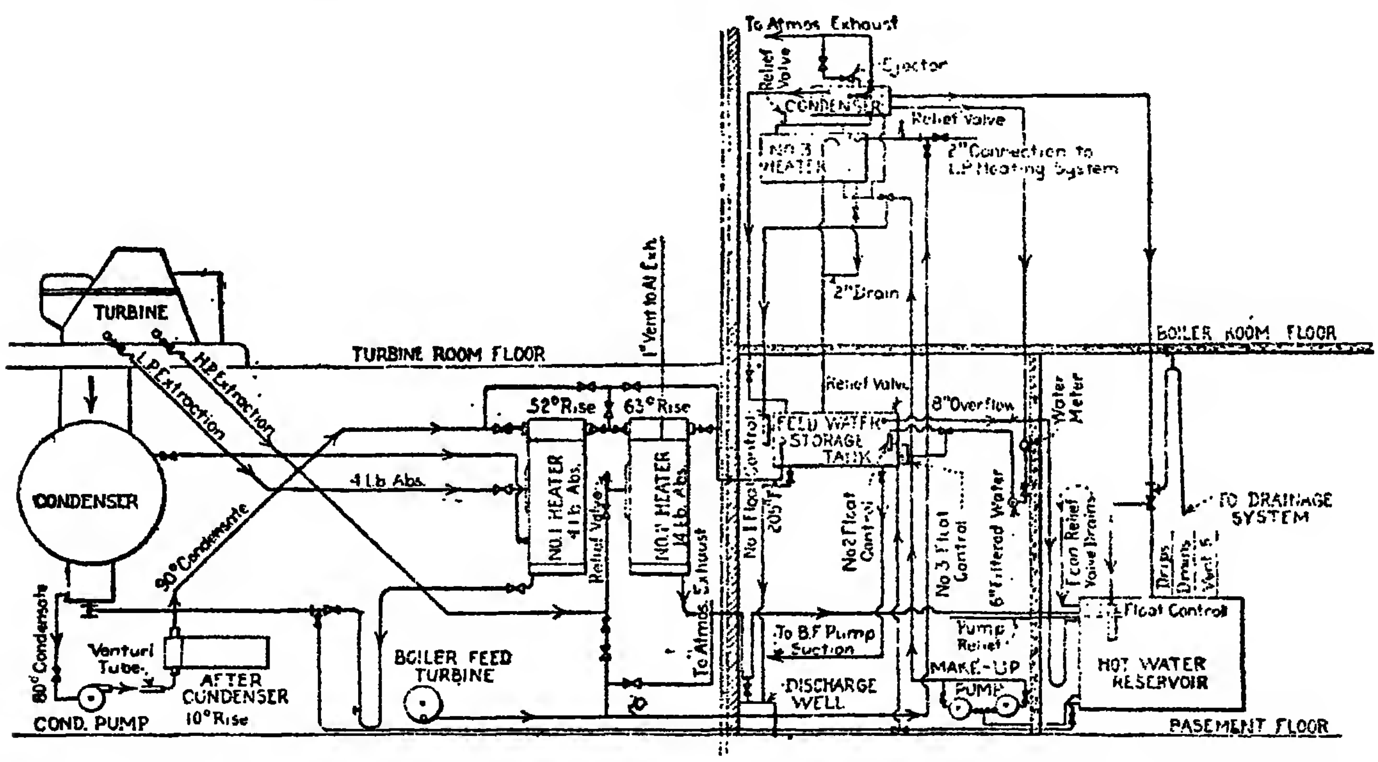

FIG. 60.—Feed-water system for Waukeegan station of the Public Service Company of Northern Illinois.

adjustments with or without main unit bleeding can be accomplished easily when the auxiliary bus supplied by the house generator operates in parallel with the main bus, but disturbances on the main bus are apt to affect the auxiliary service. Arrangements such as using double buses with a motor-generator tie, double breakers and automatic change over switches become very complicated and expensive. The trend toward direct-connected shaft-end units or the use of unit supply from transformers in the leads of each generator is simplifying auxiliary practice and at the same time permits a proper heat balance to be readily maintained. Frequently, a reserve auxiliary bus is used which is supplied by a house-turbine unit, by a transformer bank or by a motor-generator set connected to the main bus. This gives

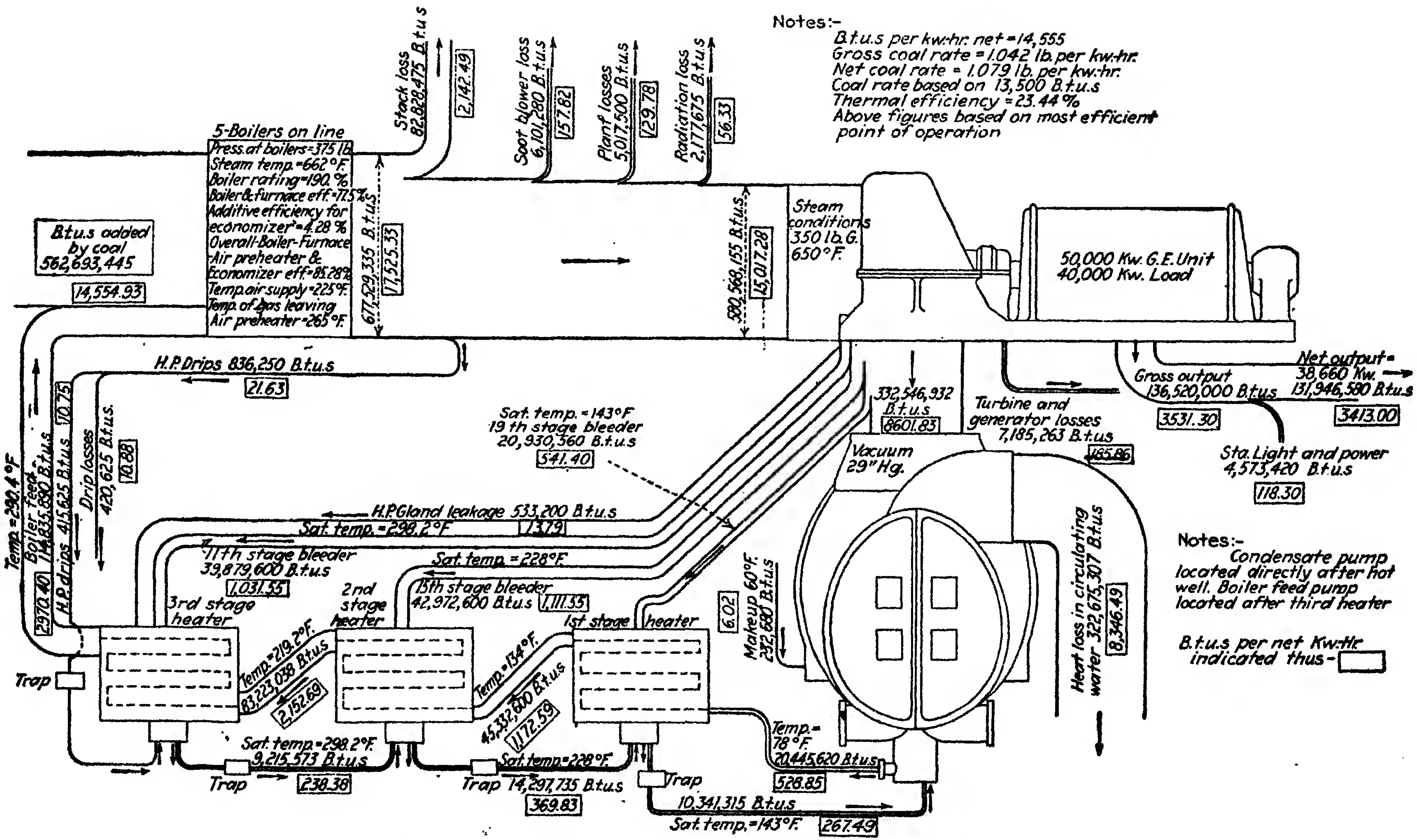

FIG. 61.—Typical heat-balance study for a 50,000-kw. unit in Richmond station of the Philadelphia Electric Company. (*E. L. Hopping, Electrical World, May 1, 1926.*)

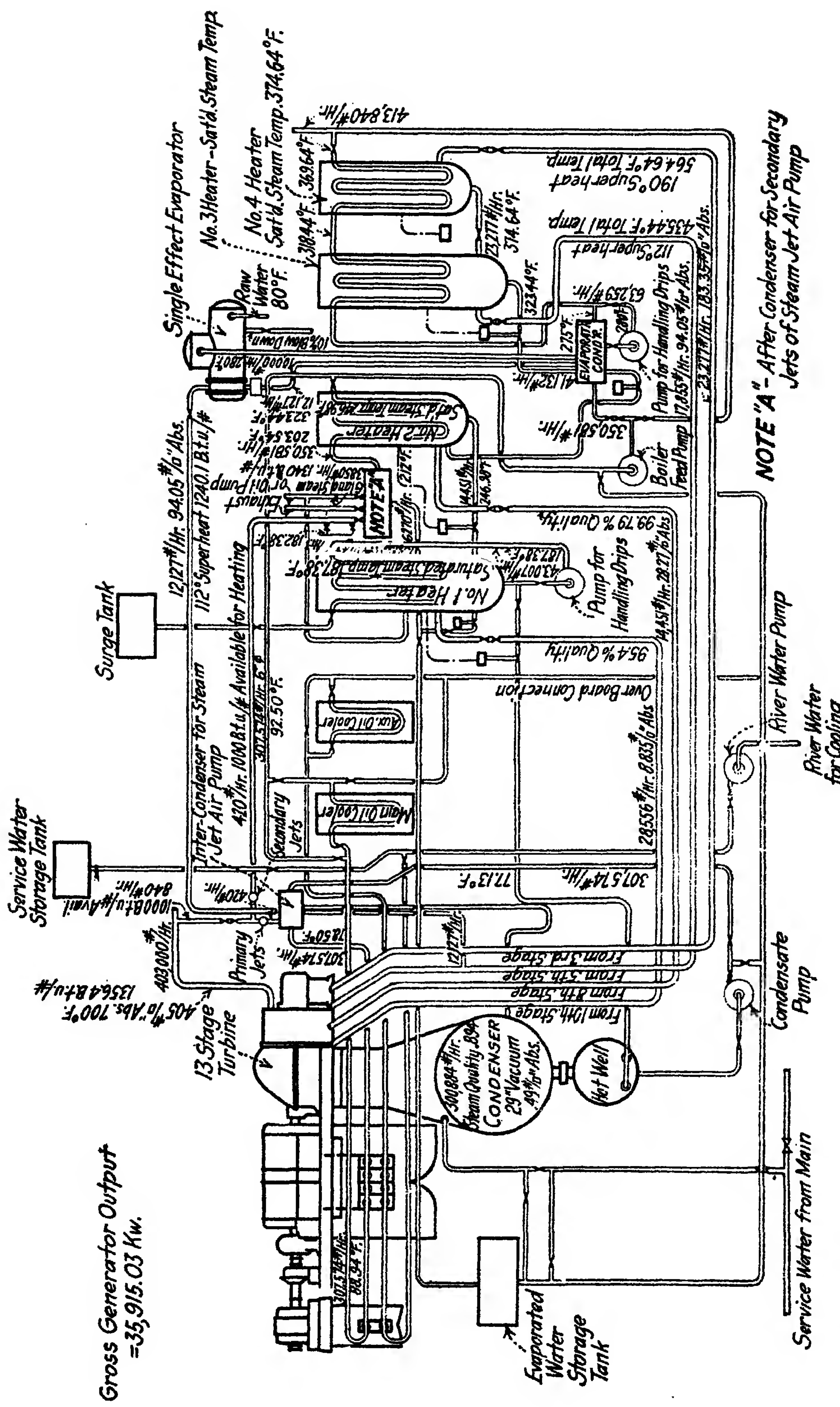

FIG. 62.—Heat-balance diagram for the Gould Street station of the Consolidated Gas Electric Light and Power Company.

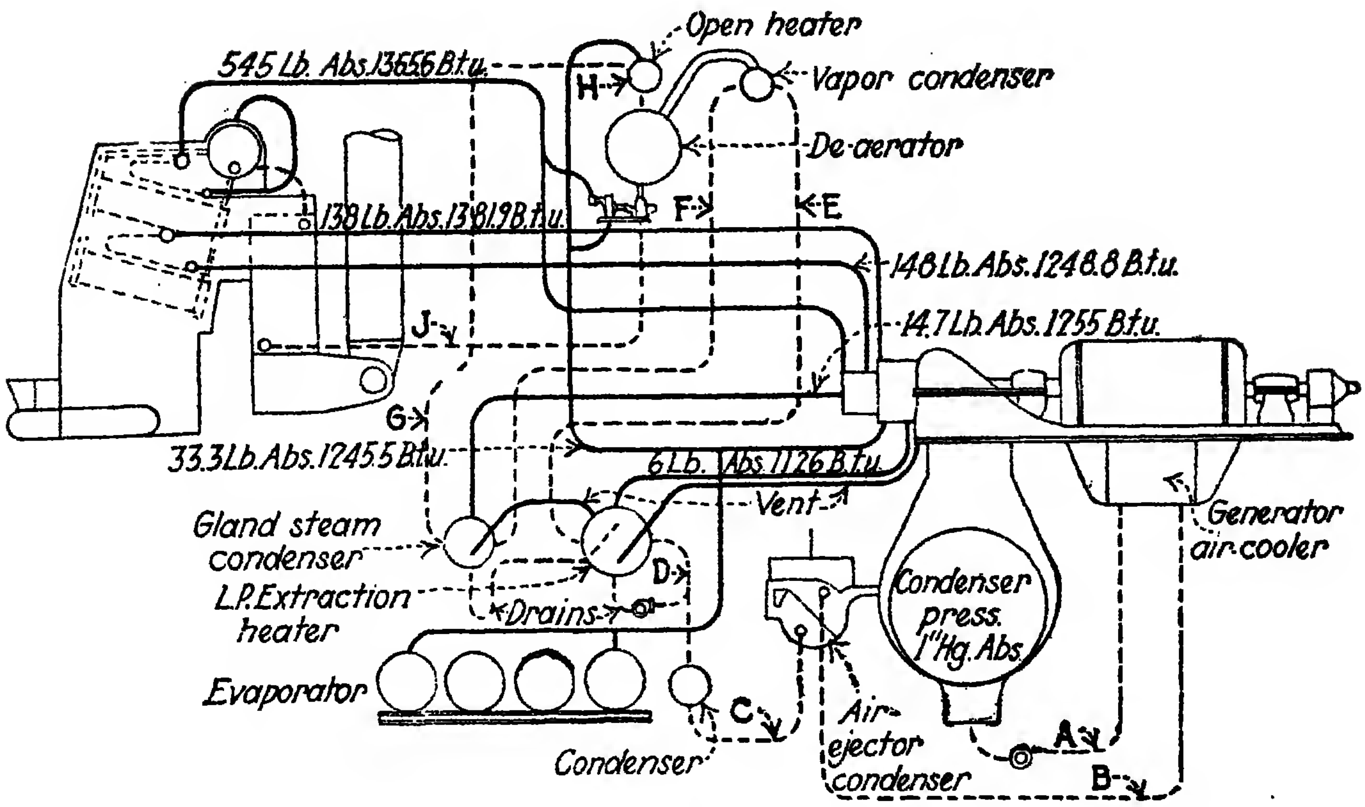

FIG. 63.—Heat flow diagram for a 35,000-kw., unit in the Philo station of the Ohio Power Company.

Boiler surface, 14,086 sq. ft. Economizer surface, 8,837 sq. ft. Efficiency boiler and economizer, 82 per cent.

	With Evaporator	Without Evaporator
B.t.u. per kw.-hr. generated	13,262	12,887
Auxiliary power	487	610
B.t.u. per kw.-hr. sent out	13,490	13,497
Operating efficiency ratio	0.90	0.90
Operating B.t.u. per kw.-hr	15,277	14,997

Water rate with reheat, 7.66 lb. per kw.-hr.
Water rate as operated:
With evaporator, 7.74 lb. per kw.-hr.
Without evaporator, 7.80 lb. per kw.-hr.
Heat in steam at throttle, 1,365.6 B.t.u.
Heat per lb. added in reheat, 133.1 B.t.u.
Heat per lb. in turbine exhaust, 985.7 B.t.u.

TEMPERATURE CONDITIONS

Temperature at	With Evaporator, Deg. F.	Without Evaporator, Deg. F.	Temperature at	With Evaporator, Deg. F.	Without Evaporator, Deg. F.
A	75	75	*F*	187	188
B	85	85	*G*	205	206
C	97	97	*H*	212	212
D	122	97	*J*	187	187
E	162	163			
Amount at 6 lb. extraction, lb				10,500	16,650
Amount at 33 lb. extraction, lb				......	1,600
Amount exhaust, lb				11,100	

AUXILIARY POWER IN KILOWATTS

Circulating pump	420	Service pump	50
Condenser auxiliaries	150	Coal handling	75
Induced draft fans	400	Miscellaneous and lighting	25
Forced draft fans	125		
Stoker motors	18	Total	1,288
Air washer	25	Boiler feed pump	372
		Total	1,660

a second and separate supply for auxiliaries under emergency conditions.

The fact that variable speed is desirable for stokers, circulating pumps and fans has caused some designers to use direct-current motors for these applications. In other instances pole-changing or brush-shifting alternating-current motors have been used and many special applications require wound-rotor induction motors. The favored motor, however, for most auxiliary drives is the squirrel-cage induction motor.

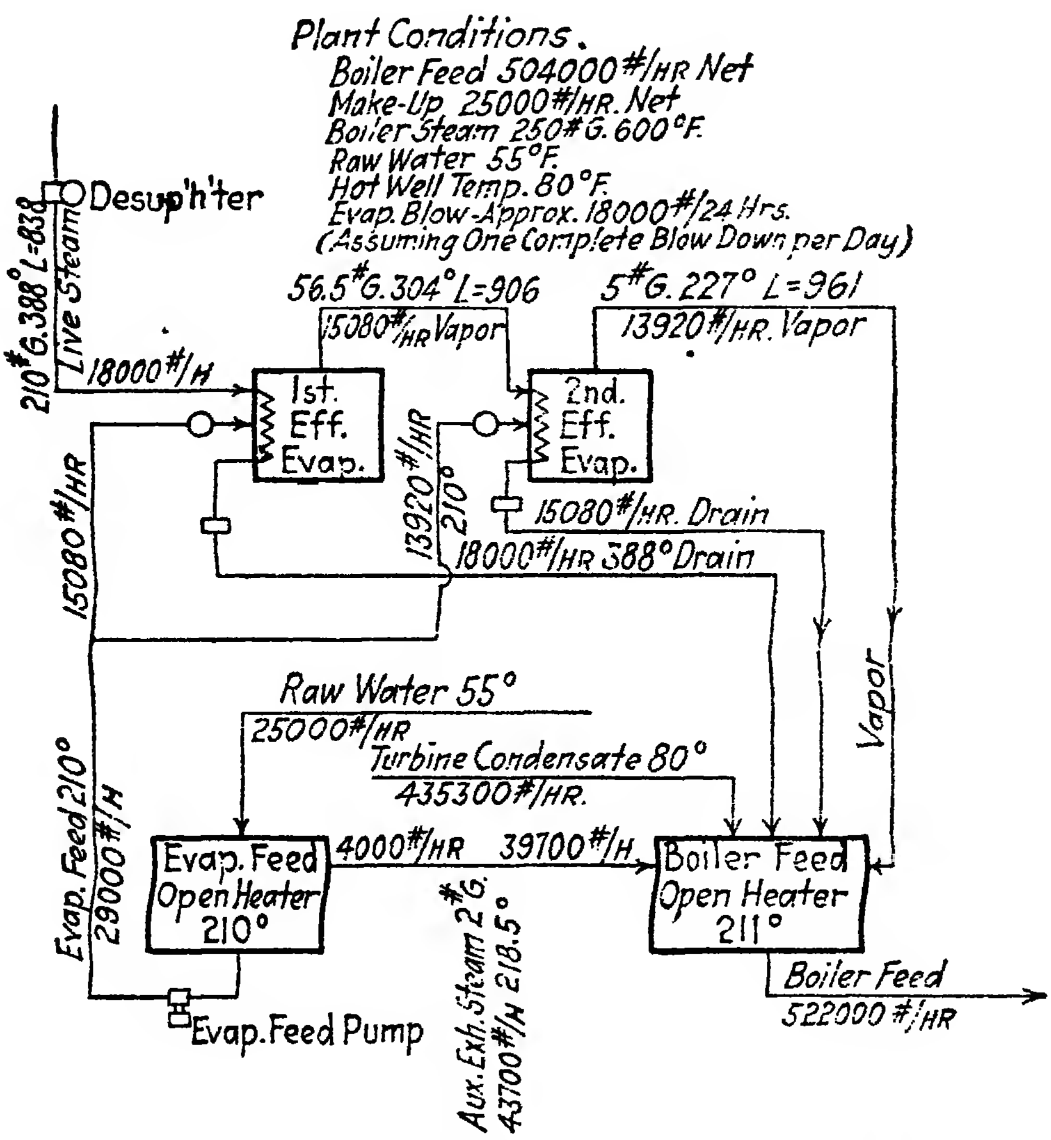

FIG. 64.—Approximate heat diagram for an evaporating plant for providing boiler feed make-up water with a two-effect pressure or low-heat-level Griscom Russell system.

A general principle for motor drives is to arrange to hold motors on the line under all service conditions. Full-voltage starting, excess-torque specifications and the elimination of low-voltage releases are usually features of auxiliary motors. Duplicate motors are often installed on fans, condensate pumps and circulating water pumps. Each motor may have the same or different ratings, depending upon conditions and opinions. Excess-torque specifications enable motors to hold their load under low-voltage

conditions and permit them to respond quickly to speed changes of the main unit.

GENERAL PRINCIPLES TO APPLY

Until the introduction and use of the auxiliary shaft-end generator most main units were equipped with a direct-connected exciter. The addition of an auxiliary generator and an exciter makes a very long main unit, so that in several cases motor-generator sets or duplex-driven exciters are used with the auxiliary generator. Where the house generator is installed, the direct-connected exciter may still be used, as the circulating pumps are then the only electrically driven auxiliaries that cannot stand a short interruption to the supply of current to the motor.

The speed of circulating pumps on large units is so slow that geared duplex-driven units would be necessary. The pole-changing squirrel-cage motor for driving the circulating pump permits of the operation of two motors at all times, even at light loads, with a relatively small consumption of power. Practically all large units have been equipped with duplex auxiliaries. This has resulted in a reduction in the capital cost per kilowatt-hour generated, on account of the greater availability of the main units and a consequent reduction in the amount of spare capacity required.

Generators supplying current to essential auxiliaries should have their individual exciters. Where these generators are operated lightly loaded and in case of emergency will have to pick up a large load automatically, either the excitation must be adjusted automatically when the load is dumped on the machine or the field must be adjusted to carry such a load at all times.

In many stations large amounts of money have been spent in complicated controls, upon which a handsome return may be earned in case high-priced fuel is burned, but an increase in the cost of power will result if this same type of equipment is installed in a plant burning low-priced fuel. In this case a simplification of the equipment can frequently be made by the use of dampers or throttling devices on control equipment, which will result in greater reliability. The use of two motors of different sizes to take the place of a single more expensive one will frequently give practically the same efficiency at the same initial cost, and in addition provide two drives for the auxiliary.

The auxiliary generator appears to be best adapted for service in stations feeding a great number of lines, in which the trouble occurring on a feeder can be limited to a local section of the station. In large stations supplying high-capacity transmission lines, external trouble is more frequently encountered and is larger in magnitude, and in this class of station the most reliable source of power supply for the auxiliaries is demanded.

Reliability is the prime essential for the auxiliary supply of any station, and although no definite rules can be stated which will apply to all conditions, it is well to consider for any station certain fundamental arrangements which have proved worth while and have been tried out. These may be stated briefly as:

1. Each main generating unit should have a separate and independent source of auxiliary power and each auxiliary should have at least two sources of power supply.

2. Those auxiliaries essential to station operation should be supplied by a separate and more reliable source of power than those auxiliaries which can have their power supply interrupted for a short period, and there should be no connection between the power supply for the essential auxiliaries and the outgoing lines from the station

3. In some applications duplicate auxiliaries should be installed to secure reliability. In other cases where the auxiliary itself is very reliable it is good practice to install duplicate drives for the auxiliary.

4. On the essential auxiliaries the motors should be able to start with full voltage. On all motors, protective devices should be simple and should operate only in the event of trouble of long duration in or near the motors.

5. Where a single power station only is installed, a house turbo-generator, a few steam-electric auxiliaries or some reserve steam-driven auxiliaries should be used so that at least one of the main units of the station can be started in operation.

Heat-balance Systems.—The full utilization of the recirculation of heat to absorb as much heat as possible in a useful way requires a definite analysis of the complete thermal performance of a station and a study of the relative advantages of different assemblies of equipments. Some things done to save heat are as follows: use of a minimum of cold make-up water, use of exhaust or bled steam to heat feed water, use of bled steam or of flue gases to heat the air required for combustion, use of the heated

air from the generators, use of evaporators for boiler feed water and use of all exhaust steam available to heat feed water.

New stations use stage bleeding of main units to heat feed water and the flue-gas air heater for heating the combustion air. The use of stage bleeding for feed-water heating has had a tendency to relegate the house turbine to emergency or standby service and to eliminate the economizers from boiler installations. The use of air heating has proved very satisfactory and the limiting factor is the effect of high furnace temperatures on equipment and refractories in the boiler furnaces.

In high-pressure stations the feed water is heated from two or four levels but when economizers are used only single or double heat levels can be used. With the use of stage heating of feed water, it has become more difficult to install feed-water evaporators that will not increase the heat requirements of the station. The greater the number of heat levels the more complicated the evaporator system and the more expensive it becomes. The use of steel-tube economizers calls for the installation of deaërators to prevent air enrichment of the condensate and the introduction of these devices adds to complexity and costs. But it is advisable to have the oxygen content of the condensate to a low value of about 0.02 c.c. per liter for satisfactory operation. Closed condensate systems have been introduced successfully to prevent air from getting into the condensate.

The feed water entering economizers is heated to at least 210°F., and, without economizer installations, and using multiple level heating by bled steam the water is heated to about 300°F. Heaters operating at atmospheric pressure are made of rolled-in tubes with U-bends for handling the condensed steam, but those operating above atmospheric pressure require traps to handle the condensed steam. Pumps are favored to return the heater condensate to the station condensate system. When superheated steam is used in the heaters the materials must be designed for the higher temperature stresses, and, depending on the effect of superheated steam, the terminal difference ranges to a minimum of about 5°F. as satisfactory for operation.

Closed heaters are vented either to a lower stage of the turbine or to a lower level heater. The deaërator type of heater is often used as a vented plant heater and the heat in the escaping vapor is condensed by the incoming cold water, but a steam ejector must be used if the pressure is above atmospheric. A Venturi

jet type of heater has been proposed, but it requires a high water velocity to lower the bled steam to a pressure below that in the main unit.

Evaporator systems to supply make-up water for boilers are now used in a majority of stations. On an average, the percentage of make-up for which evaporator capacity is installed is 3 and the source of steam for the evaporators is the extracted steam from the main units. In some cases the auxiliary or house-

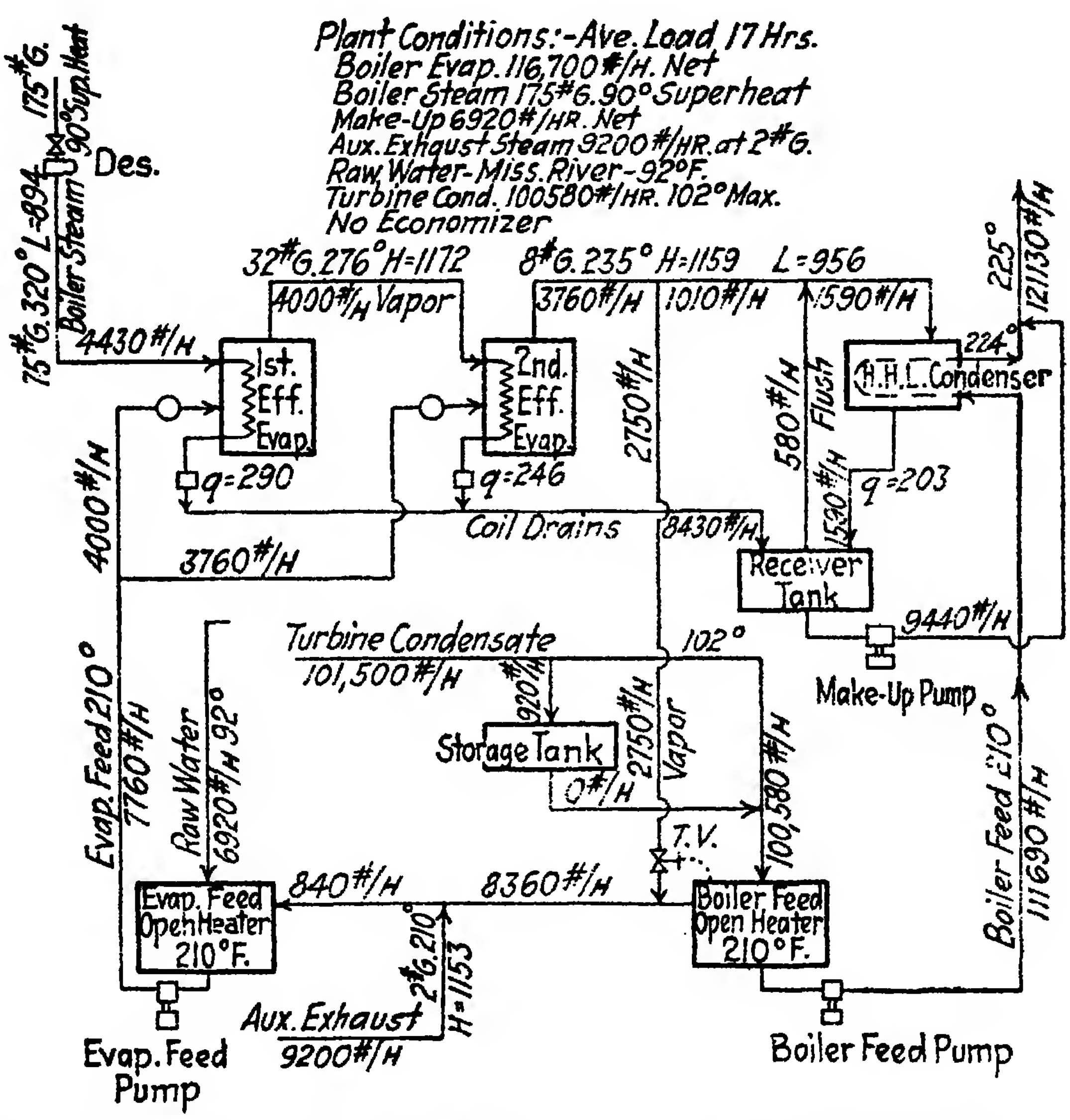

FIG. 65.—Approximate heat diagram for an evaporating plant for providing boiler feed make-up with a two-effect or high-heat-level Griscom-Russell system.

turbine exhaust and even live steam is used for the evaporator system. The vapor from the condensate is usually condensed between the second- and the third-level heaters and the steam for the evaporators is obtained from the third-level bleeding point at a temperature of about 305°. This steam, in this case, is condensed in the evaporator condenser or in the second-level heater.

In order to eliminate oxygen from boiler feed water which causes it to attack metal parts, the feed-water deaërator is often used. The deaërator is located in the condensate system where

the pressure is slightly above atmospheric and the amount of steam required to deaërate the condensate is about 2 per cent of the condensate. When exhaust steam from steam-driven auxiliaries is available it is usually discharged into the deaërator and thus makes it a plant feed-water heater also. Deaërating hot wells have been proposed and used in some plants, but data are not yet available on their performance.

The condensate should be under pressure at all times in the station feed-water system and a surge tank should be placed to give this result. The condensate should flow into and out of this tank rather than through it. Another solution much favored is

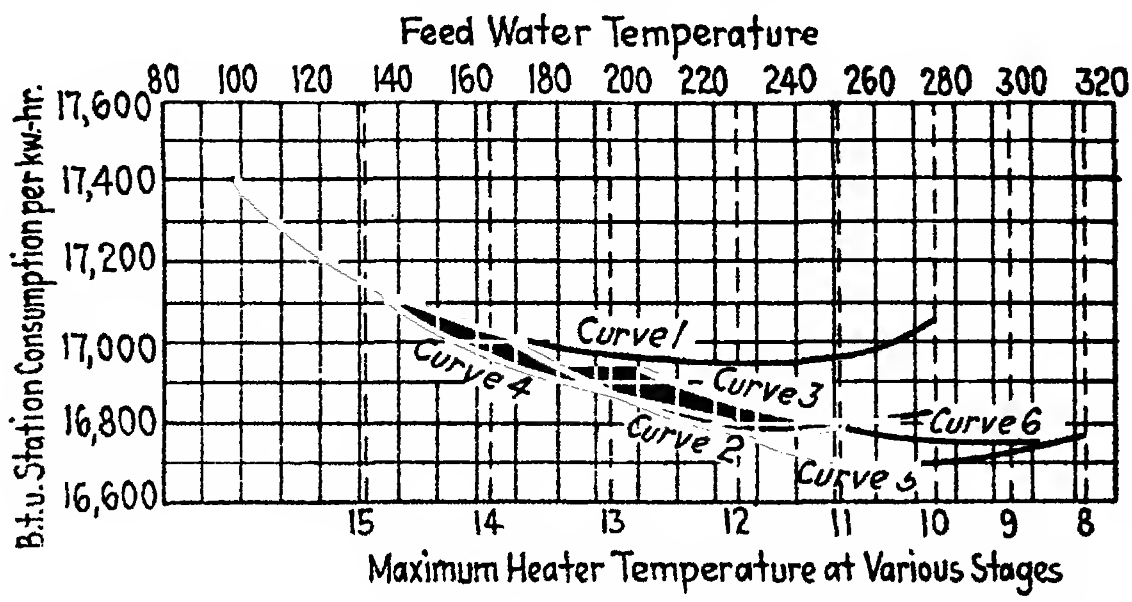

FIG. 66.—Effect of single-, double- and triple-stage extraction on feed-water temperature and station economy. Windsor station with a 30,000-kw. turbine, twenty high B. & W. cross-drum boilers, steam at throttle, 300 lb.; 200° superheat; back pressure, 1 in. Hg., no economizer, natural draft.

the use of a completely closed feed-water system which cannot take up oxygen and eliminates the necessity for use of deaërators.

When economizers are not used and bled steam is used for feed-water heating many stations introduce boiler feed make-up water into the main condenser and eliminate deaërators. This closed system has maintained an oxygen content of 0.1 c.c. per liter in the condensate successfully.

The use of bled steam for feed-water heating has tended to reduce the heat head for the feed-water evaporator when the evaporator is installed between bleeding stages. Alternative arrangements involve the installation of the evaporator condenser after the highest level heater or after the feed water has passed through the economizer. Or, when economizers are used, the evaporator condenser may be placed before the economizer, in which case the temperature rise in the economizer is reduced

about 0.3° for every degree increase in the temperature of the feed water entering the economizer. In other cases, in order to deaërate the evaporated water, the evaporator may be supplied by steam from the first- or second-level bleeder points and the vapor may be exhausted into the main unit condenser.

There is a difference of opinion as to the upper temperature to which the feed water should be heated by exhaust or bled steam, but 210° is the lowest value desirable when using steel-tube economizers in order to eliminate oxygen easily from the feed water. In a paper presented before the A.S.M.E. in December, 1922,

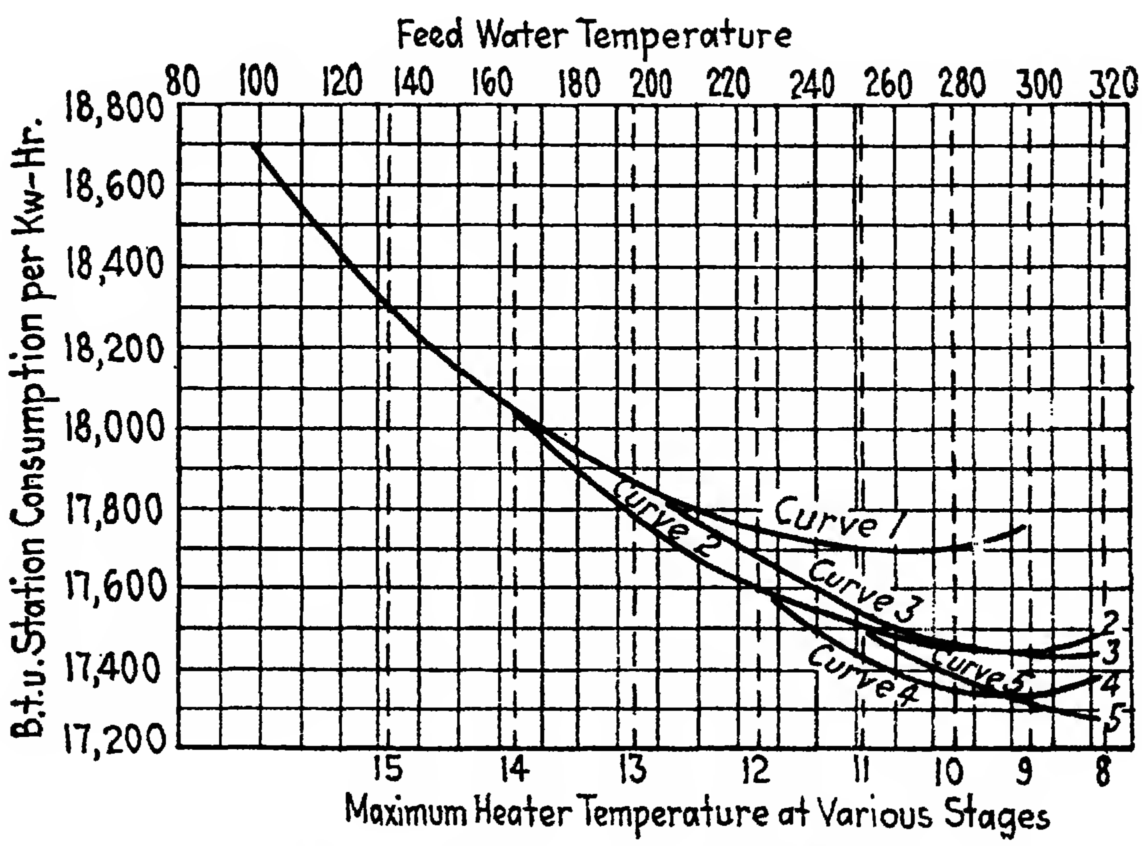

FIG. 67.—Effect of single-, double-, and triple-stage extraction on feed-water temperatures and station economy. Windsor station with a 30,000-kw. turbine, fourteen high B. & W. cross-drum boilers, steam at throttle, 300 lb.; 200° superheat; back pressure 1 in. Hg, economizer 60 per cent of boiler surface, natural draft.

Mr. Helander showed the results of theoretical studies of the subject based on a boiler efficiency of 75 per cent for a boiler alone when equipped with an economizer and of 78 per cent for a higher boiler having no economizer. The results indicated that the B.t.u. required for three-stage heating without an economizer is 1¾ per cent more than for two-stage heating with an economizer at a temperature of 333° as compared to a temperature of 245° for double-stage heating using an economizer.

An experimental study of the same subject was reported by the Prime Movers Committee of the N.E.L.A. in 1923 and the results are shown in Figs. 66, 67 and 68.

The curves in Fig. 66 show the thermal consumption obtainable with single-, double- and triple-stage heating to various temperatures, and without economizers. The curves are drawn for a given constant load.

The curve marked "Number 1" is obtained by assuming bleeding at one stage only but successively for each of the stages indicated. Maximum economy is obtainable with a feed-water temperature in the neighborhood of 260°, which corresponds roughly to bleeding from the tenth stage.

The curve marked "Number 2" indicates the most economical point to occur with a feed-water temperature of about 285°, while

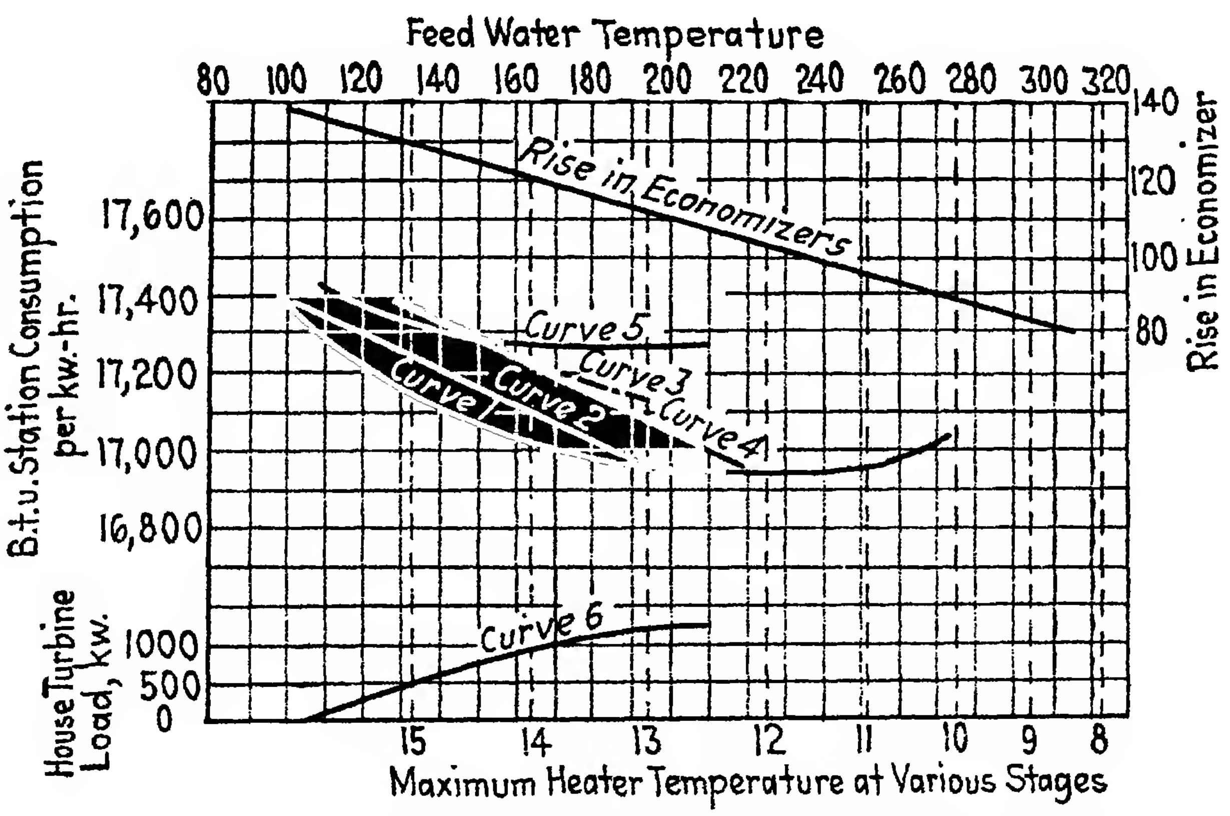

FIG. 68.—Comparison of thermal economy with house turbine and with extraction heating in Windsor station with equipment and conditions as indicated in Fig. 66.

with triple-stage heating the best result is obtained with a feed-water temperature of about 310°.

Results obtained when using single-, double- and triple-stage heating with less efficient boilers combined with economizers are shown in Fig. 67. It is interesting to note the gain indicated as obtainable by adopting stage heating in place of a house turbine. Obviously, when using any given house turbine in an actual station it must be designed for some average temperature and the performance curve will be still more concave than that shown. It is also interesting to note the feed-water temperatures corresponding to minimum thermal requirements for the station. In spite of the use of economizers, these are about 220° for single-

stage heating, 235° for two-stage heating and 260° for three-stage heating.

The practical computation of feed-water heating by bleeding is treated splendidly in a paper, "Economy Characteristics of Stage Feed Water Heating by Extraction," by E. H. Brown and M. K. Drewry, A.S.M.E., 1923.

Make-up Water.—The use of motor-driven auxiliaries results in less than 3 per cent of make-up water for the boilers, and this

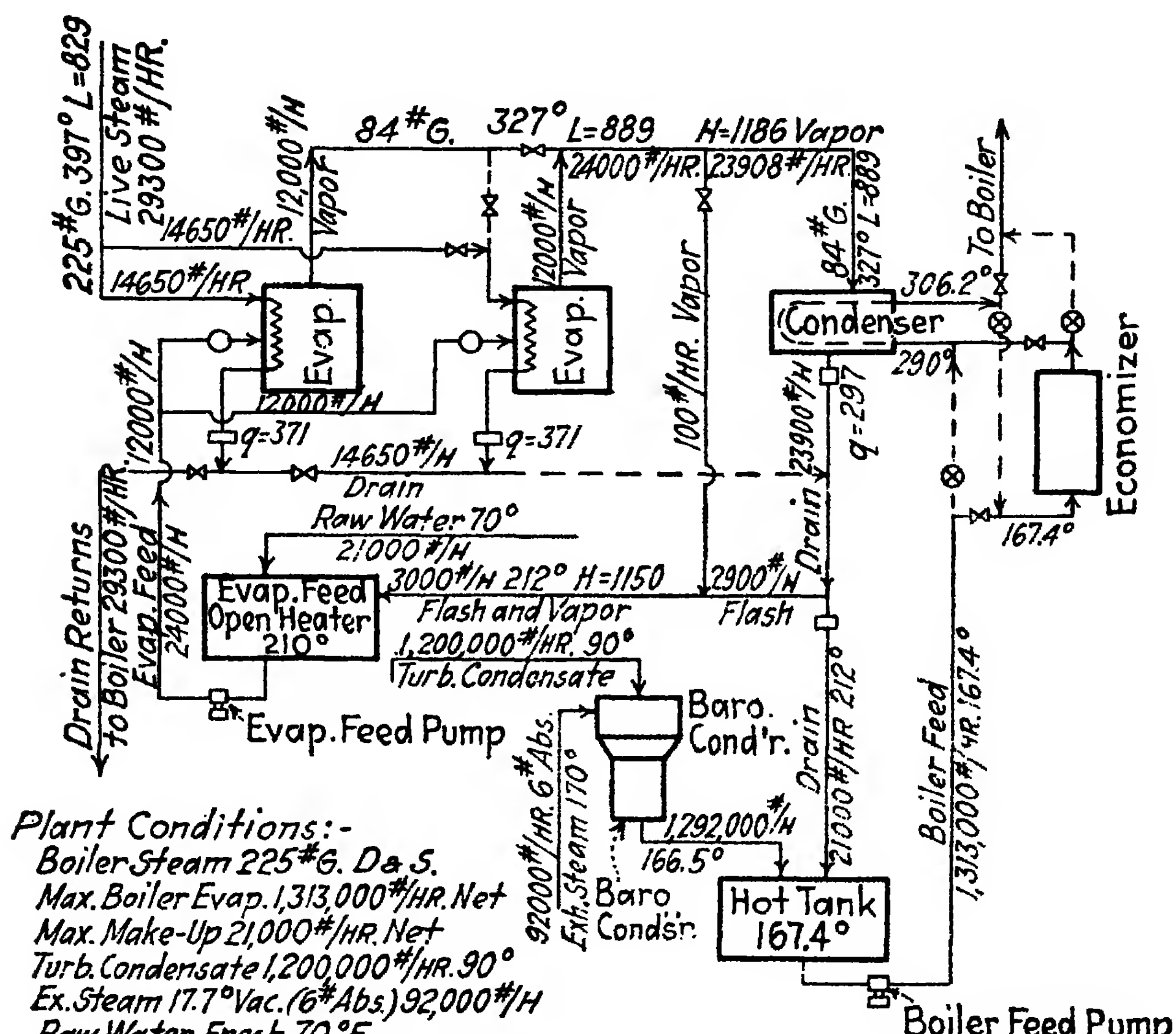

FIG. 69.—Approximate heat diagram for evaporating plant for providing boiler feed water make-up. Single-effect, high-heat-level Griscom-Russell system.

small amount together with the increased impurity of natural water supplies makes it economical and advisable to have evaporated make-up water. To secure this evaporated water a high-pressure evaporator system may be used which operates at slightly less than boiler pressure and uses the boiler feed water to absorb the vapors at about 212°F., or a low-pressure evaporator system may be used which works at or below atmospheric pressure and a vacuum of 20 to 25 in. of mercury and uses the condensate to absorb the vapors. The high-pressure system may be used with double or triple effect.

The evaporators operate with a unit temperature difference between the steam and vapor ranging from 30 to 100° and Table XIX gives data on an evaporator system when the evaporated water equals 4 per cent of the amount of the boiler evaporation and the evaporator feed temperature is 70°F.

TABLE XIX.—TEMPERATURE RISES AND TEMPERATURE DIFFERENCES FOR EVAPORATORS[1]

Number of effects	Rise in temperature by absorbing vapor from elevator and drain from coils	Rise in temperature from absorbing vapor from evaporator only	Ordinary difference between temperature of saturated steam supplied to evaporators and inlet temperature of boiler feed entering evaporating condenser
1	48	40	100–125
2	28	18	165–200
3	21	11	200–250

[1] N.E.L.A. Prime Movers Committee, 1923.

The following discussion on evaporator systems is taken from the *Report* of the Prime Movers Committee of the N.E.L.A., 1923.

The following are a few of the general schemes of connecting the evaporators into the steam, exhaust and condensate systems:

First.—High-pressure evaporator, most commonly double effect, working with saturated steam at approximately boiler drum pressure, the vapor being discharged to the plant feed-water heater. This type of system is referred to as "low-heat-level." A typical arrangement is shown in Fig. 64.

The condensing of the evaporator vapor in the boiler-feed open heater is only efficient in cases where this increase of temperature will not cause a temperature in the heater exceeding the convenience of power station heat balance. If the temperature in the boiler-feed open heater, without evaporators, is as high as can be permitted, the absorption of evaporator vapor would then displace auxiliary exhaust or bleeder steam in equal amount. While this arrangement does not waste any heat, the plant is not utilizing the opportunity to generate a certain amount of power very cheaply, as steam bled from the main unit or steam from the house turbine develops power at the turbine for the heat equivalent of a kilowatt plus the radiation, friction and generator losses, or approximately 4,000 B.t.u., whereas if an equal amount of power has to be developed by steam expanded to the pressure in the condenser of the main unit, the heat charged against the turbine is approximately three to four times as much.

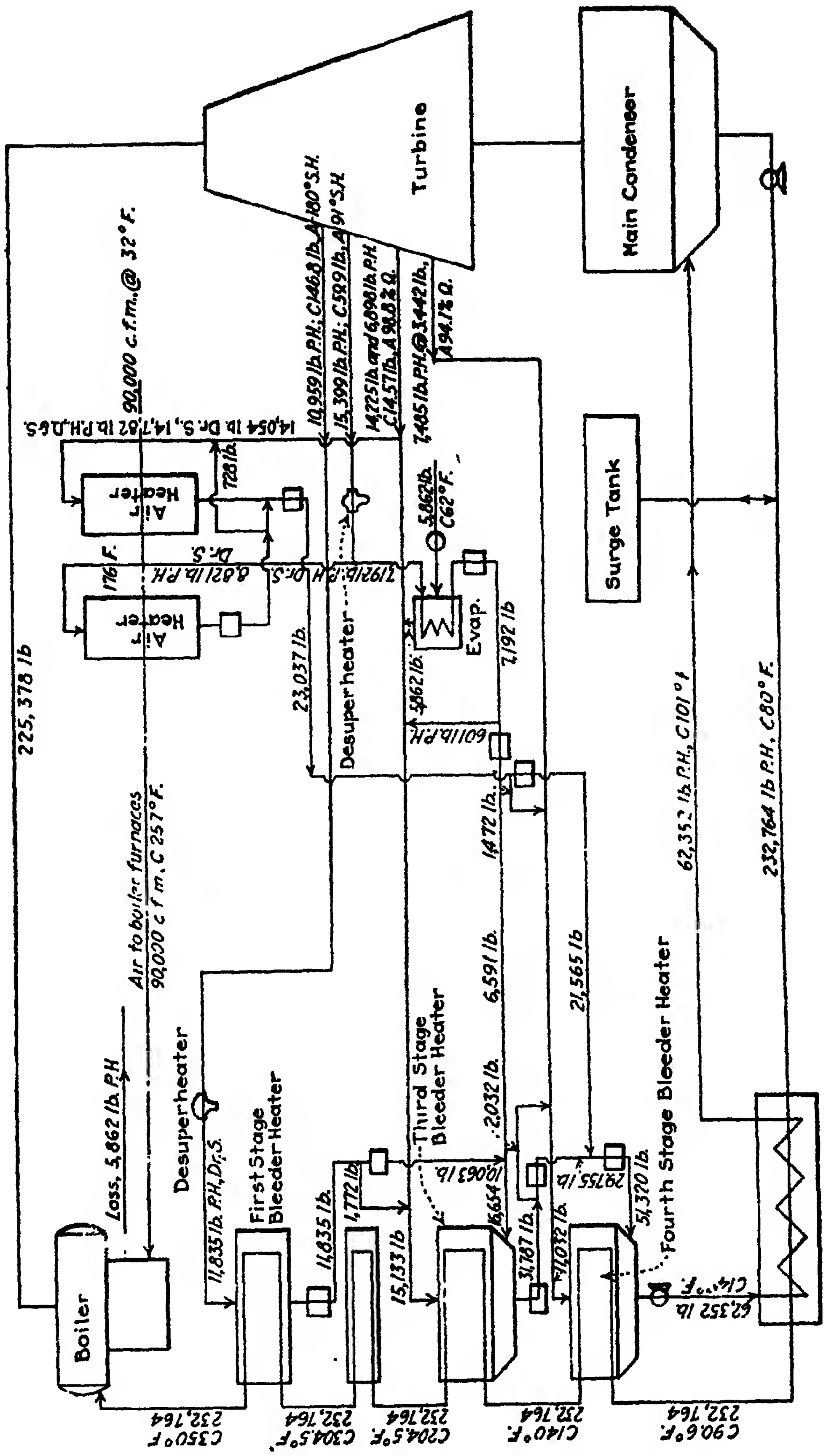

FIG. 70.—Heat-balance diagram for a 20,000-kw. peak-load station. (G. T. Shoemaker, *Electrical World*, Sept. 1, 1923.)

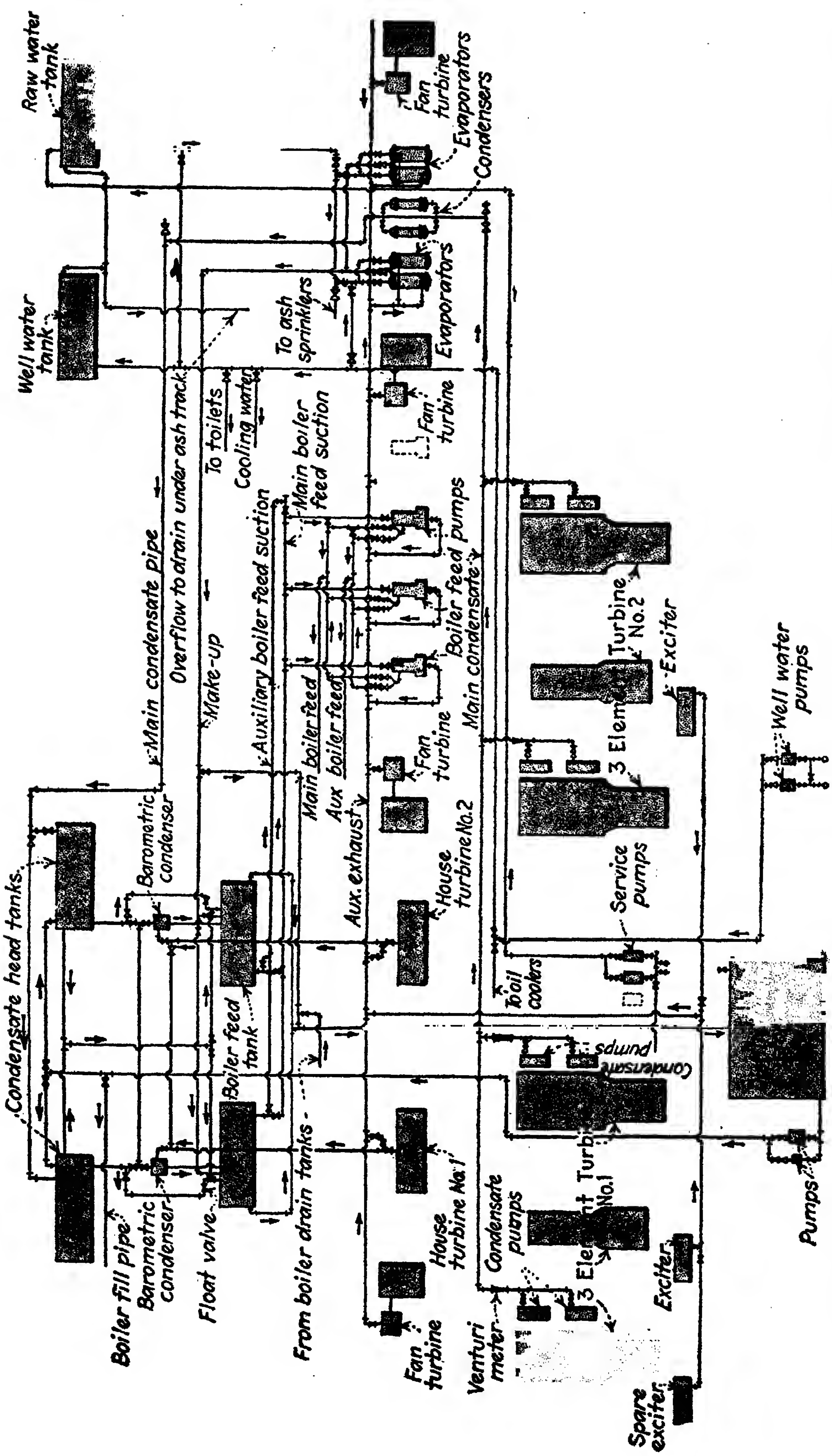

FIG. 71.—Method of using auxiliary exhaust, double-effect evaporators, barometric feed-water heater and a house turbine to maintain a heat balance in the Colfax station of the Duquesne Light Company.

In case the evaporator vapor displaces steam bled from the main unit, the reduction in the amount of 4,000 B.t.u. power which can be obtained from the main unit is between two-thirds and seven-eighths of 1 per cent of its maximum output, when the average amount of make-up is 2 per cent of the maximum amount of water evaporated by the boilers.

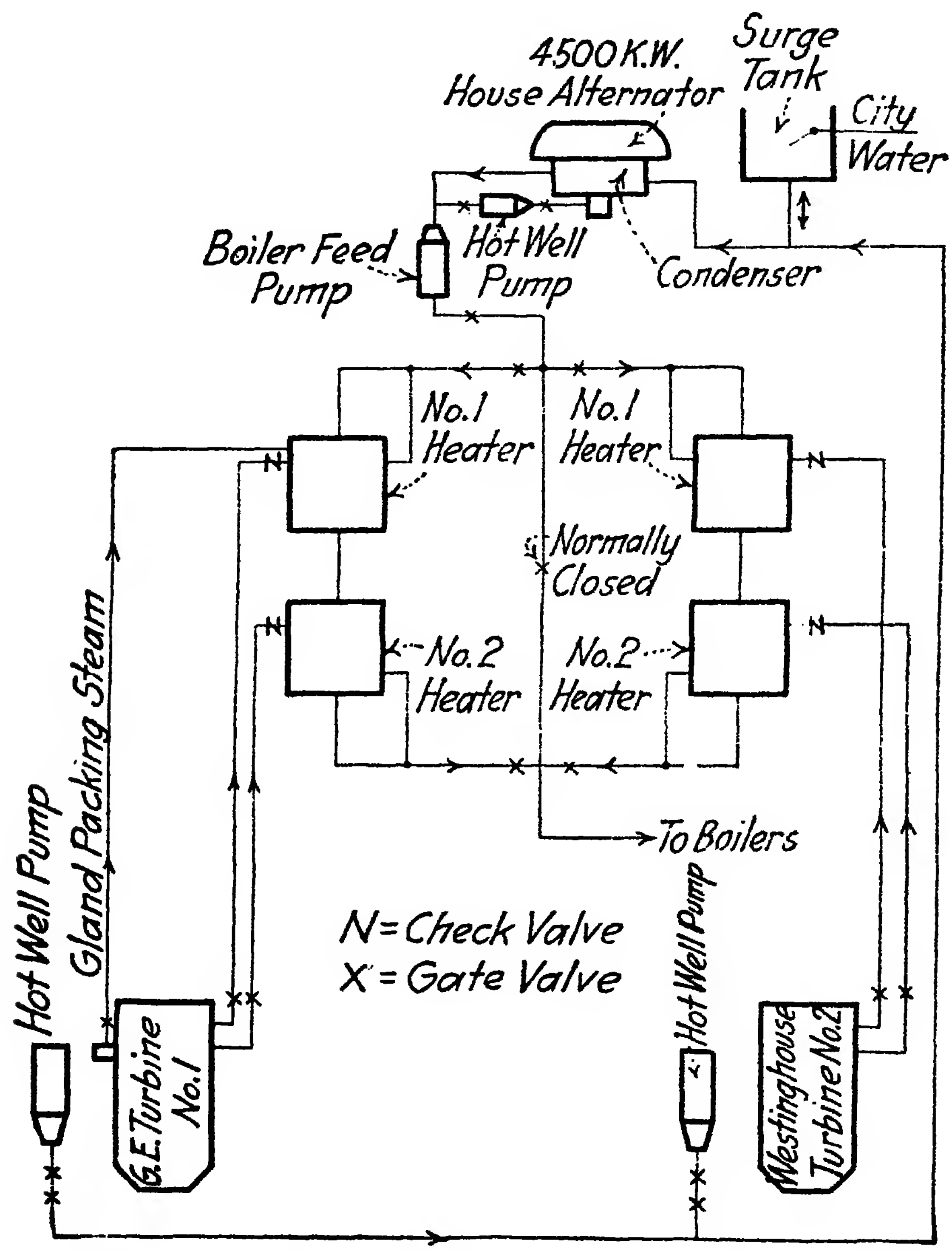

FIG. 72.—Heat-balance diagram for Hudson Avenue station of Brooklyn Edison Company.

Second.—The disadvantages of the arrangement just described can be overcome if, in place of discharging the vapor from the evaporators into the plant heater, the vapor is condensed by the boiler feed water in a closed heater located between the boiler feed pump and the boiler. This is commonly referred to as a "high-heat-level" evaporator system. Such an arrangement has the slight disadvantage that the evaporator condensor must be built for full feed-water pressure. However, such condensers are in service in several plants, and are operating satisfactorily.

The only losses in this system are those due to radiation and to blow down at a temperature in excess of 210°F. These losses are but about

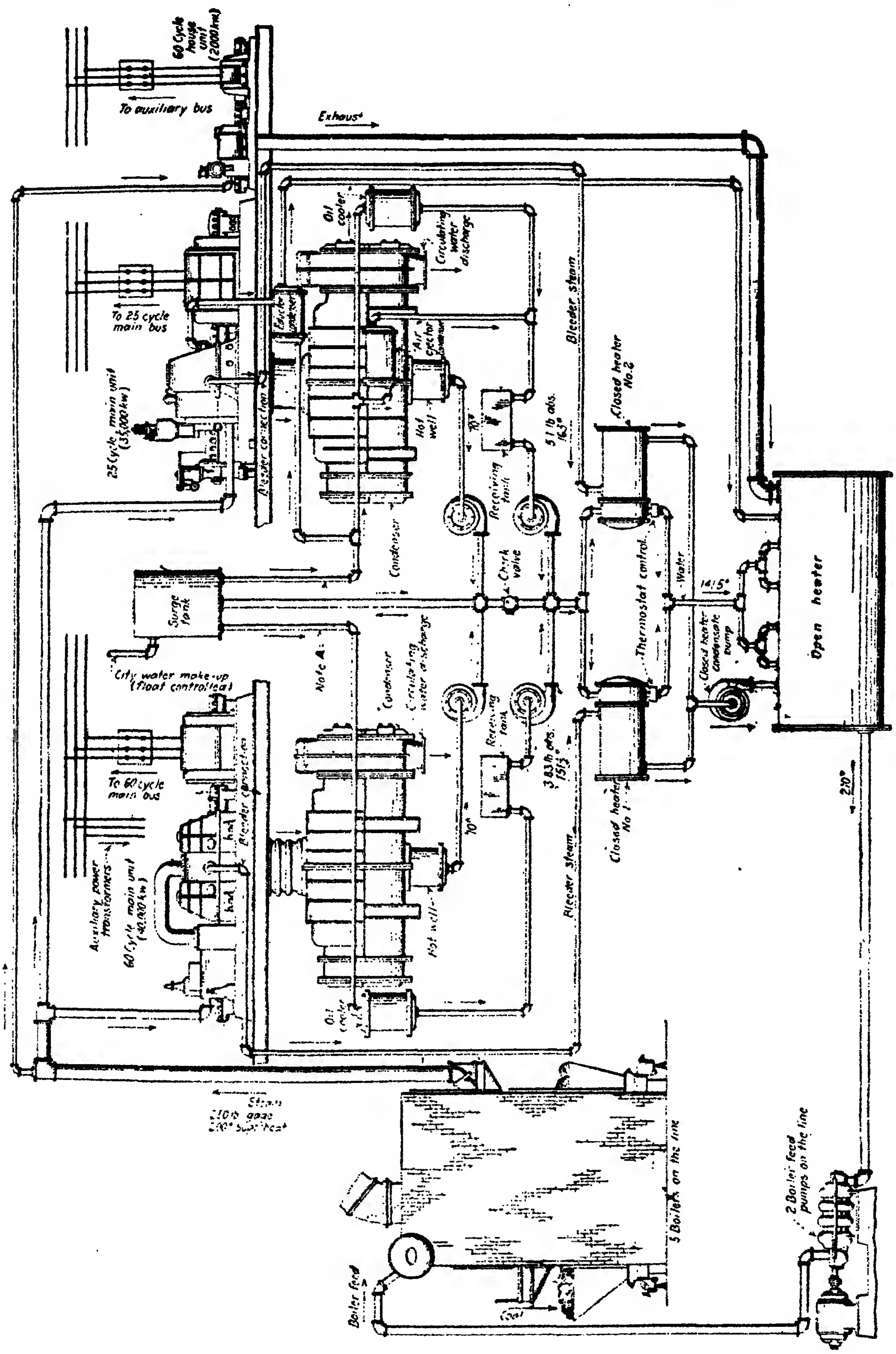

FIG. 73.—Diagrammatic layout of heat-balance arrangements in Hell Gate station of the United Electric Light and Power Company.

2 per cent of the heat passing through the evaporator in the average case and may be disregarded.

The arrangement of equipment and quantities for a typical case is shown in Fig. 65.

This arrangement can be used when economizers are installed, the boiler-feed water absorbing the heat of the vapor before entering the economizer. With a double-effect evaporator and 2 per cent make-up, this would increase the temperature of the water entering the economizer about 14°, or with a triple effect, about 10°. The temperature rise through the economizer would then be decreased about 4° for the double-effect and 3° for the triple-effect evaporator. The corresponding increase in coal requirements in an 18,000 B.t.u. station would be of the order of 0.28 to 0.376 per cent. The loss from this source would be about two-thirds of the loss with the first arrangement.

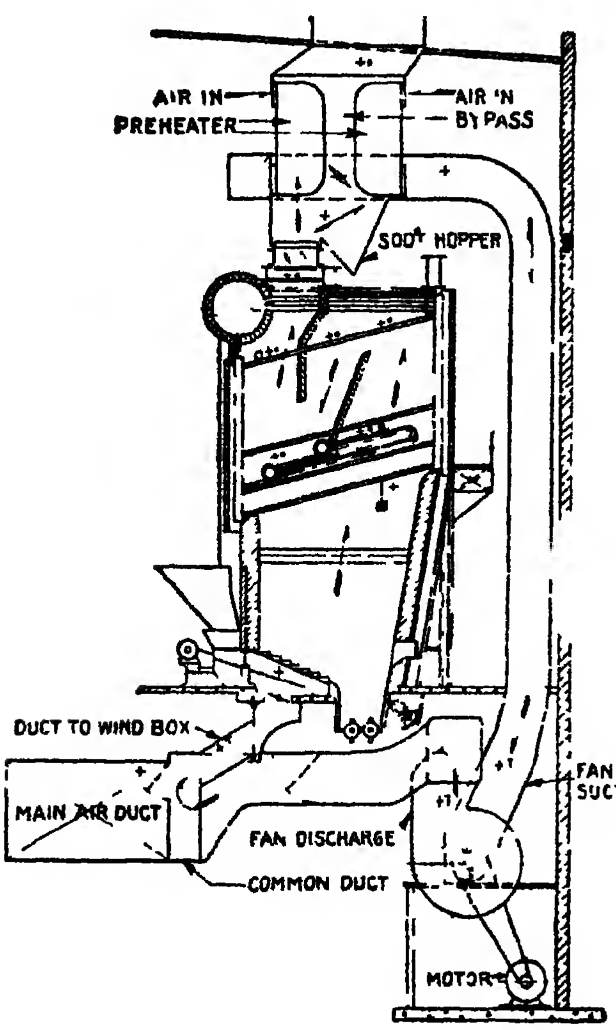

Fig. 74a.

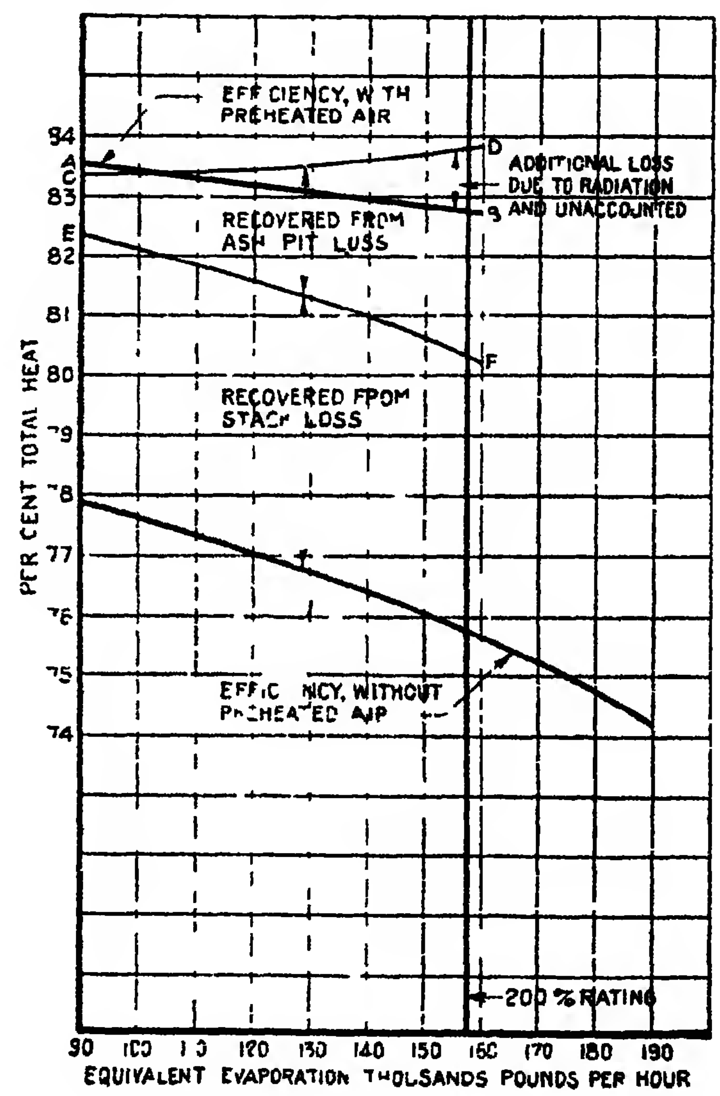

Fig. 74b.

Fig. 74.—Boiler test results with preheated air in Colfax station. (a) General arrangement of boiler and preheater system. (b) Distribution of difference in efficiencies. (C. W. E. Clark, A.S.M.E., 1923.)

Third.—In a plant in which multi-stage bleeding is used a great many arrangements of evaporating equipment are possible. There appears to be a tendency toward the use of high-pressure evaporators with absorption of evaporator vapor heat at high temperature by the feed water on its way to the boiler. If an economizer is not installed, it is probable that the second scheme described above would be adopted, that is, the heat from the vapor would be absorbed by the feed water after the latter has been heated by steam bled from the turbine. Two of the later plants are putting in high-heat-level condensers, and absorbing the heat from the evaporators at temperatures in excess of 300°.

This arrangement with a properly chosen final temperature will probably be the most efficient to use with multi-stage heat extraction, with or without economizers and with single-effect or two-effect evaporators.

The range in temperature between boiler drums and boiler feed water, after the latter has been heated to the most efficient temperature for double- or triple-stage heating without economizers, or after the economizers when there has been single- or double-stage heating, is about sufficient for a single-effect evaporator. This scheme causes no heat losses other than radiation and high-temperature evaporator blow down. Of course, the loss in the blow down can be largely conserved through heat exchangers if their use can be justified on an economic basis.

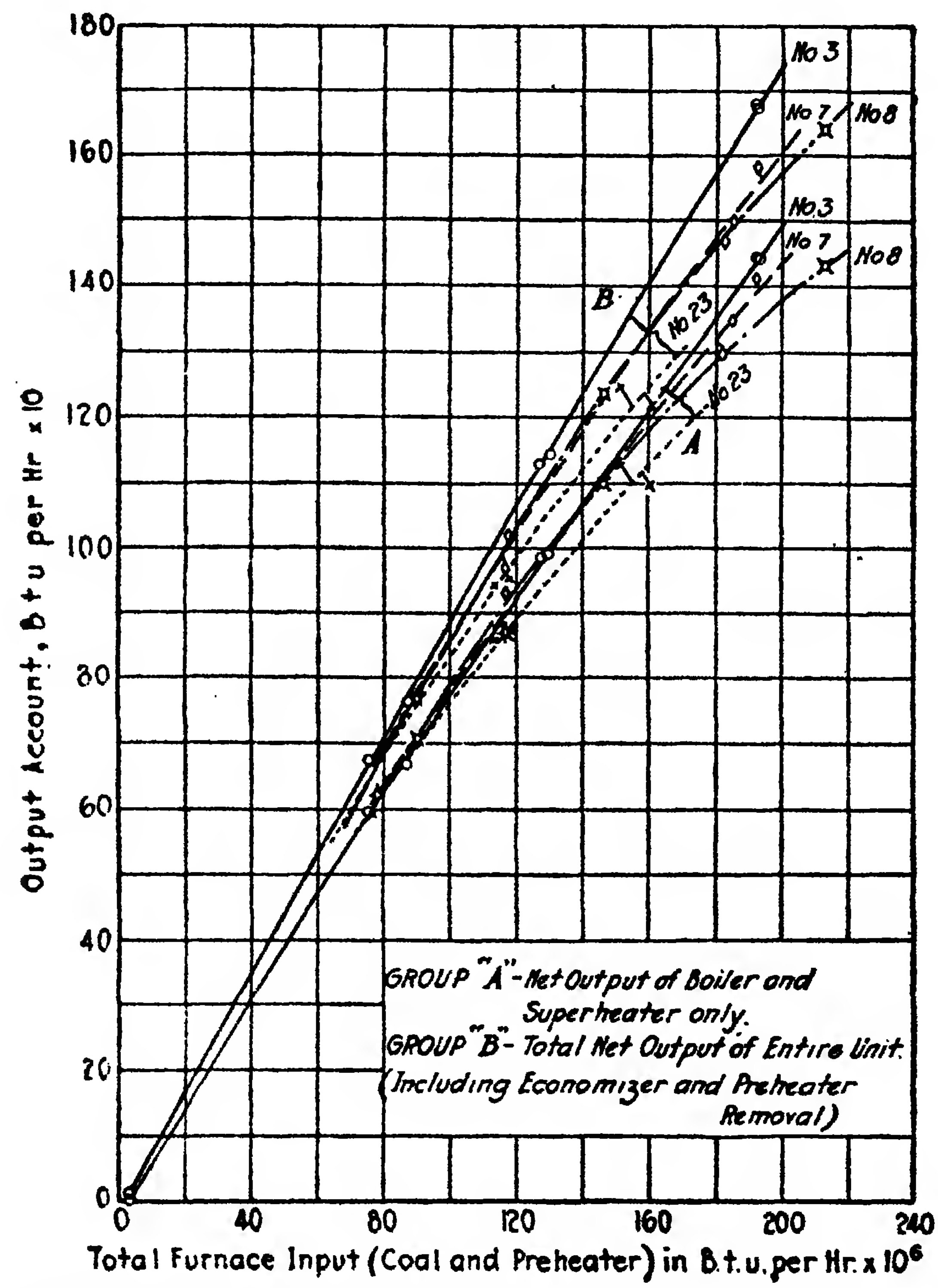

FIG. 75.—Relation of total heat output to total heat input. (*N. E. Funk, A.S.M.E.*, 1926.)

Interchange of heat at high temperature has been tried out in the Navy with the idea of heating the boiler feed water to approximately

steam temperature before entering the boiler. There seems to be no reason why heaters cannot be built for this purpose, but so far there has

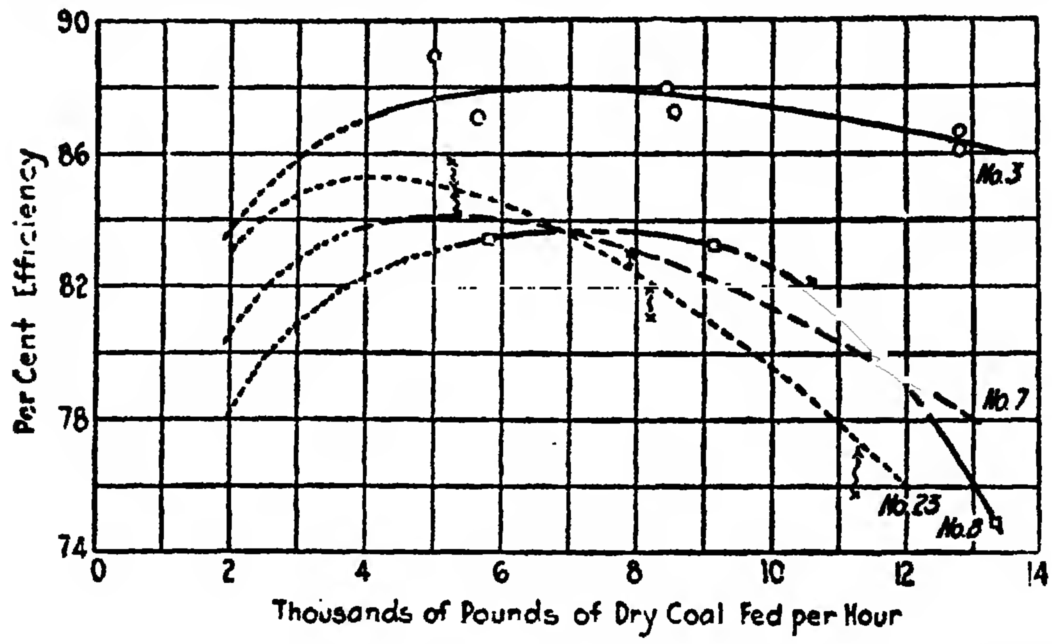

FIG. 76.—Relation of boiler efficiency to rate of fuel feed. (*N. E. Funk, A.S.-M.E.*, 1926.)

$$\text{Per cent efficiency} = \frac{\text{Heat to steam} \times 100}{\text{Heat of coal fired}}$$

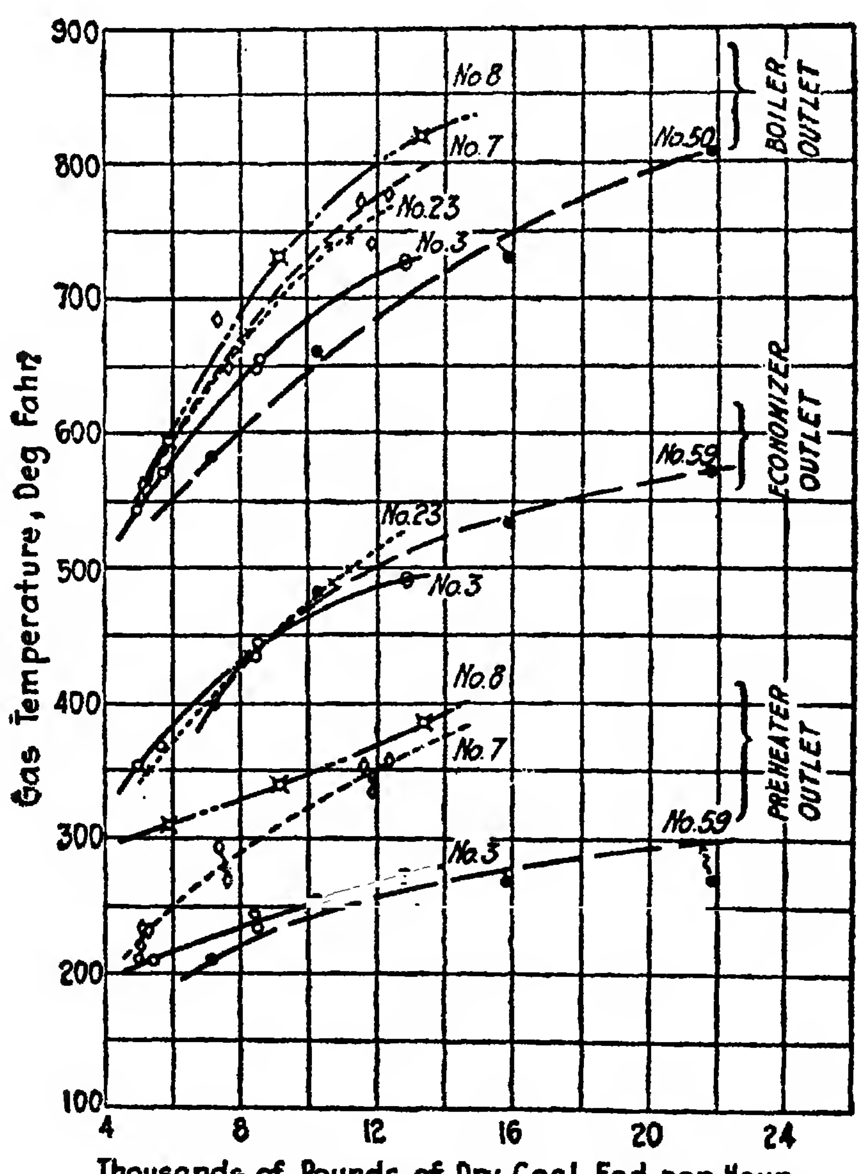

FIG. 77.—Relation of gas temperatures to rate of fuel feed. (*N. E. Funk, A.S.M.E.*, 1926.)

been a scarcity of practical experience with them in connection with evaporators.

One method of arranging evaporators for this scheme is shown in Fig. 69. Blow-down connections and heat interchangers have been omitted for simplicity. The diagram actually shows a case in which the feed water is heated in a barometric condenser instead of by stage heating, but this is immaterial so far as the upper part of the diagram is concerned. The evaporators and high-heat-level condenser are so arranged that by different valve settings the system may be operated

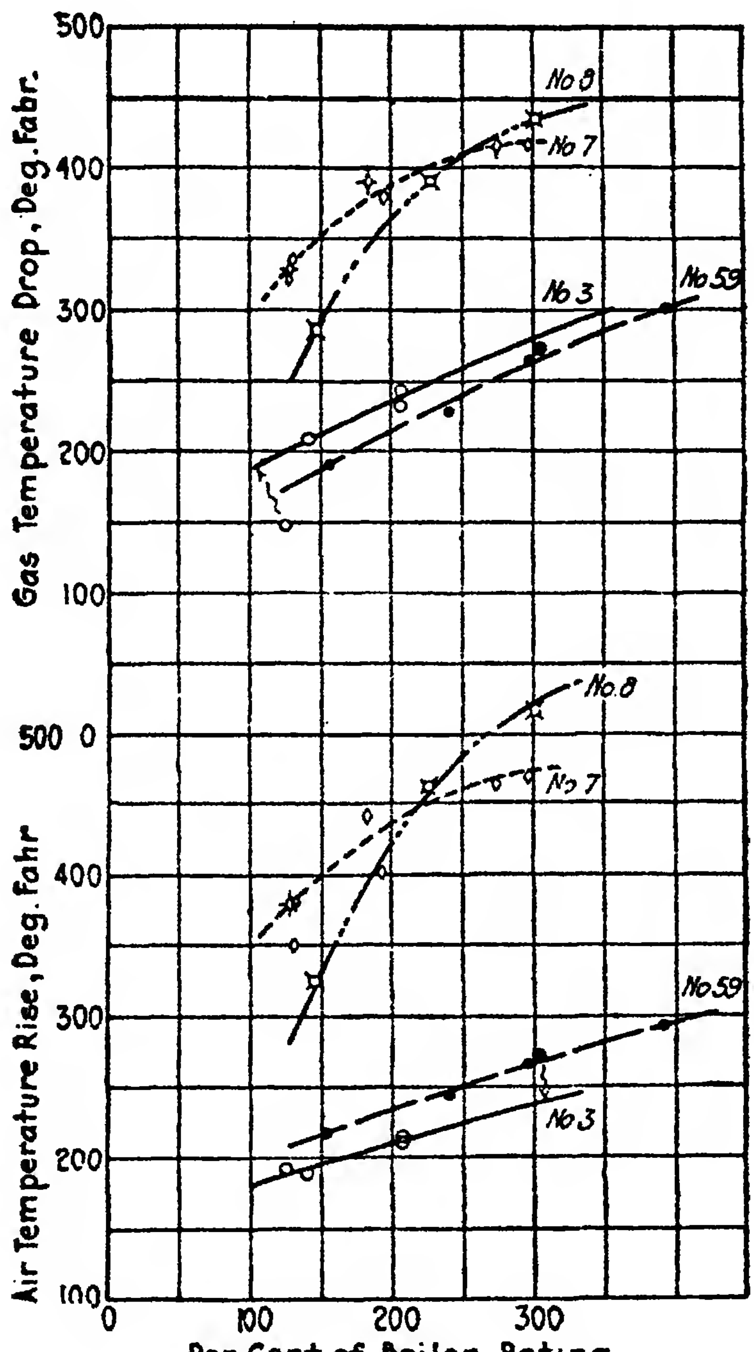

Fig. 78.—Temperature changes through air preheaters. Relation of gas-temperature drop and air-temperature rise to boiler rating. (*N. E. Funk, A.S.M.E.*, 1926.)

as a multiple single-effect with the high-heat-level condenser between economizer and boiler, or as a two-effect with the high-heat-level evaporator preceding the economizer. This affords great flexibility for meeting the requirements of various fractional loads.

Air Pumps and Heaters.—The steam-jet air pump of the inter-cooler type is very frequently used alone or in combination with the hydraulic pumps. The usual method of recovering the steam

used by the first stages of the ejectors is to trap the water from the intercooler back to the main condenser and that of the last stages is taken to the surface condensers in which the condensate absorbs the heat and the air is permitted to escape. The condensed steam then is returned to the evaporator hot well.

Air separation by deaërators is practiced when steel-tube economizers are used. In one type of deaërator the condensate is heated 15 or 20° above the temperature of delivery to the economizer and then boils in a vacuum after cascading over trays. The heat in the vapor often is absorbed by the condensate before it goes to the deaërator heater. In another type of deaërator, exhaust steam of sufficient temperature to boil the condensate is passed through coils placed in contact with the condensate causing it to boil. If the pressure is below atmospheric a vacuum is maintained. If the steam comes from the main unit its heat must be given the condensate before it enters the deaërator heater, and in the usual arrangement the deaërating equipment provides all or most of the storage supply for the boiler-feed pump.

The use of deaërators limits the amount of heat which can be absorbed from main unit steam from the lower stages, as this bleeding must occur at a pressure corresponding to the temperature to which the condensate must be heated for air extraction and the exhaust steam must be hot enough to heat the condensate about 25°F.

Closed heaters prevent oxygen getting into the condensate, prevent the flow of steam into the turbine when stage bleeding is used if the pressure at the bleeding point falls below the vaporization temperature of the material in the heater and permit the use of a minimum number of pumps for handling water. They are used in practically all cases when bleeding is practiced, although they are more expensive than jet condensers, require a higher temperature head and are difficult to arrange for air extraction.

Jet condensers or open heaters are usually restricted for use with exhaust steam from sources such as auxiliaries and main unit glands. Their chief disadvantages are that they permit oxygen to be absorbed and are difficult to install on bleeder systems.

Oil Coolers.—The oil used in turbine bearings and power transformers becomes heated and some of this heat may be

absorbed by the condensate, but this usually involves rather complicated piping arrangements, as there must be a reserve cooling source and there is no direct relation between condensate flow and oil temperature. Figure 79 shows an arrangement of condensate oil cooling used by one company.

Air Heaters Successful.—Air may be heated in a station by the generators, by extracted or bled steam or by stack gases. In some cases the heated generator air is taken to the boilers, but the thermal gain is slight and the costs are often quite heavy. On the other hand, very good possibilities are offered for heating combustion air by use of stack gases or bled steam.

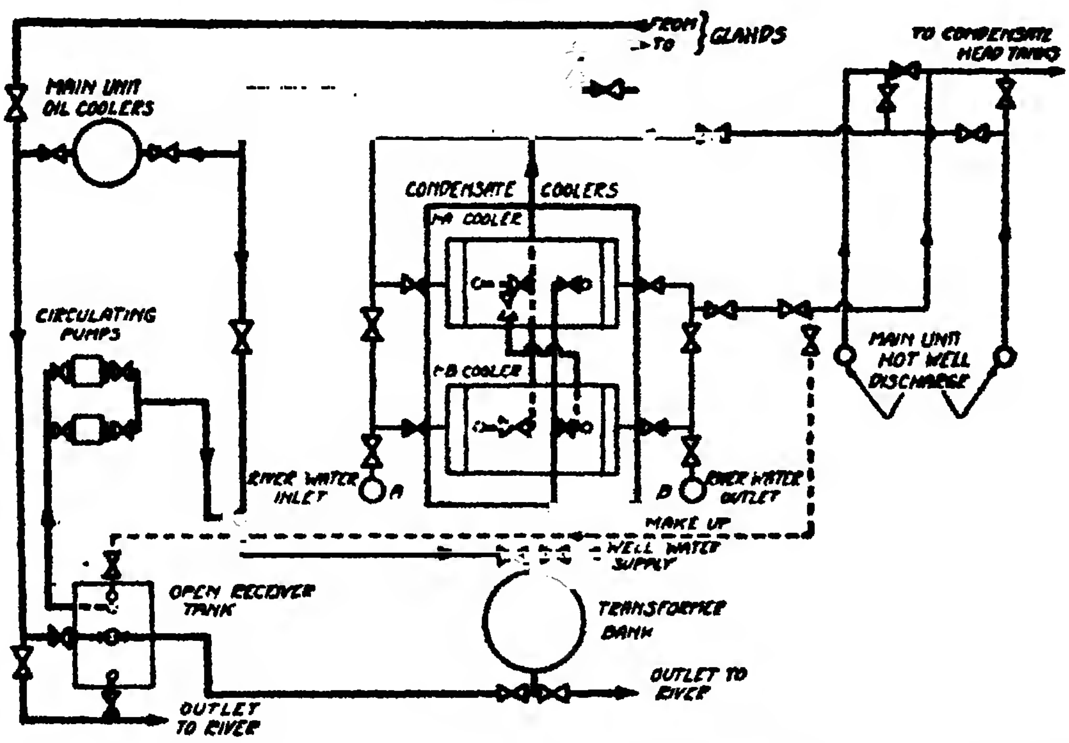

FIG. 79.—Condensate oil-cooling system in Colfax station of Duquesne Light Company.

Recent tests in several stations on combustion air heating have proved very successful and many new stations have recently installed air heaters. Figure 74*a* and *b* shows the equipment and the results obtained in tests at the Colfax plant of the Duquesne Light Company as reported by C. W. E. Clarke to the A.S.M.E. in 1923. The tests were made on a B. & W. boiler having 22,914 sq. ft. of heating surface, 7,500 cu. ft. of furnace volume and 2,999 sq. ft. of superheating surface located in the first pass. The pressure was 275-lb. gage and 11,200 sq. ft. of preheating surface was used.

The following abstract of a paper presented at the Providence meeting of the A.S.M.E., May 5, 1926, gives a resume of test results with different types of air heaters as made by N. E. Funk, operating engineer of the Philadelphia Electric Company.

TABLE XX.—BOILER INSTALLATION CHARACTERISTIC
(B. & W. Stirling boilers, 55 tubes wide)

Station	Boiler number	Date installed	Heating surface: Boiler	Heating surface: Superheater	Heating surface: Economizer	Heating surface: Preheater	Heating surface: Water wall	Economizer feed temperature, degrees Fahrenheit	Approximate final steam condition: Pounds per square inch, gage	Approximate final steam condition: Total temperature, degrees Fahrenheit
Chester	3	Dec. 31, 1924	14,217 sq. ft. 100 per cent	2,582 sq. ft. 18.15 per cent	5,250 sq. ft. 36.95 per cent	22,072 sq. ft. T 154.8 per cent	....	172	257	652
	5	Feb. 14, 1925	14,217 sq. ft. 100 per cent	2,582 sq. ft. 18.15 per cent	5,250 sq. ft. 36.95 per cent	20,719 sq. ft. P 145.7 per cent	....	172	257	652
	6	Dec. 6, 1924	14,217 sq. ft. 100 per cent	2,582 sq. ft. 18.15 per cent	5,250 sq. ft. 36.95 per cent	22,500 sq. ft. P 158.2 per cent	....	172	257	652
	7	Feb. 5, 1925	14,217 sq. ft. 100 per cent	2,582 sq. ft. 18.15 per cent	....	64,960 sq. ft. L 457.0 per cent	....	172	257	652
	8	June 1, 1925	14,217 sq. ft. 100 per cent	2,582 sq. ft. 18.15 per cent	....	50,276 sq. ft. T 353.5 per cent	....	172	257	652
Delaware	23	July 5, 1924	14,217 sq. ft. 100 per cent	2,582 sq. ft. 18.15 per cent	6,853 sq. ft. 48.2 per cent	....	....	167	257	633
Richmond	59	Oct. 8, 1925	15,692 sq. ft. 100 per cent	2,822 sq. ft. 17.9 per cent	7,515 sq. ft. 47.85 per cent	22,072 sq. ft. T 140.7 per cent	595 sq. ft. 3.79 per cent	235	410	658

T, Tubular air heater; L, Ljungstrom heater; P, Plate type heater. (N. E. Funk, 1926.)

An extended description of the seven boiler settings covered by the tests is summarized in Table XX compiled to permit a ready comparison of the units. Table XXI gives the stoker characteristics. The differences in stokers and furnace volume will have some effect on the boiler efficiency, but the general designs are so nearly the same that a comparison of air-preheater performance is but slightly affected.

Table XXII gives the physical characteristics of all the preheaters with the exception of the Ljungstrom, which cannot be compared with the others on the same basis.

In comparing the characteristics of these preheaters with each other and with a boiler without any preheater, the boiler numbers have been placed on all the curves to indicate to what units they particularly apply. To review the physical characteristics of the units compared, the following tabulation gives the economizer and the air-preheater equipment of each one of the boilers.

TABLE XXI.—STOKER CHARACTERISTICS

(American Engineering Company, Taylor, Type H.C. 7)

Station	Unit number	Grate surface, square feet	Number of rams	Number of tuyères	Furnace: Volume above asphalt, cubic feet	Furnace: Height of mud drum from floor, feet	Ash pit at heel of fire: Width, feet	Ash pit at heel of fire: Depth, feet
Chester	3	310	15	21	6,650	11	3.8	5.3
	5	310	15	21	6,650	11	3.8	5.3
	6	310	15	21	6,650	11	3.8	5.3
	7	310	15	21	6,650	11	3.8	5.3
	8	310	15	21	6,650	11	3.8	5.3
Delaware	23	310	15	22	7,200	13	3.8	4.0
Richmond	59	337	15	25	7,780	13	3.8	5.3

Boiler Number	Equipment
3	Economizer and small tubular air preheater
5	Economizer and small plate preheater, Connery type
6	Economizer and small plate preheater, B. & W. type
7	Ljungstrom air preheater only
8	Large tubular preheater only
23	Economizer only
59	Economizer, small tubular air preheater and water wall

TABLE XXII.—PREHEATER CHARACTERISTICS

Boiler number	3	5	6	7	8	59
Heating surface, square feet	22,072	20,719	22,500	64,960	50,276	22,072
Type	Tubular, B. & W.	Plate, Connery & Co.	Plate, B. & W.	Rotary, Ljungstrom	Tubular, B. & W.	Tubular, B. & W.
Rows of tubes	15	. . .	.....	.....	41	15
Tubes per row	90	. .	.....	.....	75	90
Tube diameter—or thickness of gas passage, inches	$2\frac{1}{2}$	$\frac{5}{8}$ (gas)	$1\frac{1}{4}$	.....	$2\frac{1}{2}$	$2\frac{1}{2}$
Metal thickness	12 B w.g.	$\frac{1}{16}$ in.	16 B.w.g.	.....	12 B.w.g.	12 B.w.g.
Length of tube, feet	25		....	.....	25	25
Overall duct height, feet	..	15	24			
Overall duct width	..	3 ft., 2 in.	4 ft.			
Number of gas ducts		252	99			

The performance of boiler and economizer units equipped with air heaters is compared on the basis of total heat injected into the furnace, including the heat in fuel and air above atmospheric temperature.

In Fig. 75 are two familiar curves. Group *A* indicates the output of the boiler and superheater alone. Group *B* indicates the output of the entire unit including economizer and preheater. It is to be noted that the performance of the boiler alone without preheated air is poorer than that of any of the boilers using preheated air and that except at fairly high rating there is little difference in the performances of those using preheated air at low and those using preheated air at high temperatures. With the increase in rating, however, the boiler supplied with preheated air at low temperature maintains a much higher output ratio than do the two supplied with preheated air at higher temperature.

The author has no doubt of the accuracy of the tests of units 7 and 8 so far as their relation to the test of unit 3 is concerned, but is inclined to believe that, although these were the actual performances obtained from the boilers, they are not indicative of what may be expected with highly preheated air. His belief is based on two outstanding conditions which prevent the attainment of high efficiency with these units. First, at high ratings the furnace refractories will not stand up under the higher preheated-air temperatures and it is necessary to reduce the percentage CO_2 somewhat to preserve the furnace walls. Second, with the greater quantity of heat liberated in the furnace, the boiler alone apparently does not absorb as much and the temperature of the exit gases rises rapidly. This puts an extra burden on the air preheaters.

The first condition can be met by water-cooled furnace construction. The second condition can be corrected by the installation of increased boiler surface or a change in boiler baffling. These two points are emphasized because there might be a tendency, from analysis of these curves, to assume that the use of a preheater without an economizer is, in general, productive of lower efficiency. This is true for the particular design tested, but the author feels that there are errors in design and that the lower efficiency is not a fundamental characteristic of high preheated-air temperatures.

The *B* group of curves substantiate the conclusions drawn for the *A* group. It will be noted, however, that the curves for

units 7 and 8 are much closer together than those of the *A* group, which indicates that the tubular preheater is performing somewhat better than the Ljungstrom preheater.

Attention is called to the fact that unit 3 shows a still better performance than either 7 or 8, since the deviation of the curves for these units and that for unit 3 is greater in the *B* group than in the *A* group. This, however, is due largely to the fact that the economizer reduces the flue-gas temperatures so that the air temperatures do not rise so rapidly as they do in 7 and 8.

Figure 75 does not give a true comparison of the efficiencies of the boiler units for a given amount of fuel consumption, but does give the performance of the boiler surface. For this reason, curves have been plotted in Fig. 76 showing the efficiencies of these units at different rates of fuel consumption. These are overall efficiencies of boiler, superheater, economizer and air preheater. There are distinct differences in the shapes of these efficiency curves. Unit 23, which has no preheater, shows a rapid drop in efficiency with increase in rating. Unit 3, which is practically the same as 23, except that an air preheater has been supplied, shows an unusually flat efficiency curve.

The efficiencies of units 7 and 8 which have the large air preheaters are distinctly lower than the efficiency of 3, although they are somewhat flatter than and at heavy loads higher than 23. Unit 8 shows a rapid dropping off in efficiency, not due to the characteristics of highly preheated air, but to the fact that the boiler furnace is not properly designed to care for the high temperatures. The rapid downward bend in the efficiency curve of unit 8 is accompanied by severe burning of the extension grates of the stoker. This is apparently caused by the reflected heat from the bridge wall, and if the performance of a stoker with a similar ash-discharge end can be used for comparison, the installation of a water-cooled wall at this point would raise by 3 or 4 per cent the lower end of the curve for unit 8.

In Fig. 77 comparative data are given on the boiler, economizer and preheater outlet-gas temperature. Attention is called to the fact that both units 7 and 8 with the highly preheated air have higher outlet temperatures than unit 23 with cold air. Unit 3, however, with a preheated-air temperature of 300°F., has an outlet-gas temperature considerably lower than that of unit 23, and unit 59 with the water-cooled walls has a lower temperature than any of the others. The economizer outlet temperatures

are approximately the same for all units having economizers, that of unit 3 being somewhat lower than that of 59. The increased temperature of economizer outlet gas in unit 59 is primarily due to the fact that the feed-water temperature is 63° higher than that of unit 3.

The air preheaters on 3 and 59 are identical, and the exit gases from these two preheaters are at practically the same temperature. The air preheaters on 7 and 8, however, have considerably higher exit-gas temperatures, due apparently to the higher exit temperatures of gas from the boilers. This condition is more clearly shown in Fig. 78 in which the temperature drop in the flue gas

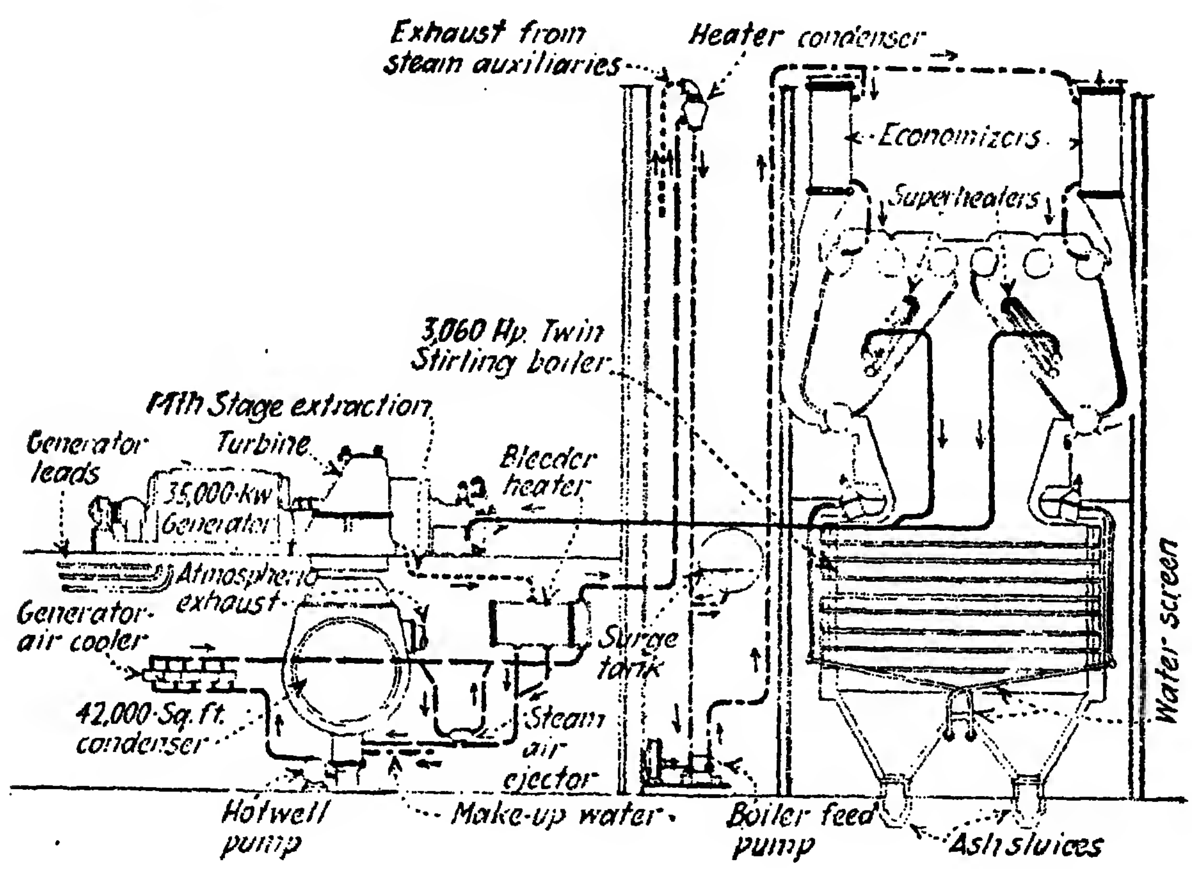

FIG. 80.—Steam, condensate and feed-water system in Avon station of the Cleveland Electric Illuminating Company.

and the temperature rise in the air supplied to the stoker have been plotted against percentage of boiler rating. In this figure, as in Fig. 77, it will be noted that the air preheaters of units 3 and 59 are almost parallel in performance, 59 showing a somewhat better heat transfer than 3. These preheaters were tested under practically the same condition of cleanliness. Preheaters of units 7 and 8 reduce the gas temperature and increase the air temperature through a range from 50 to 80 per cent greater than the smaller air preheaters. This is to be expected on account of the larger area of heating surface.

Computation of Heat Balance.—The computation of the heat balance of any station requires a study of thermal performance

at every stage from coal pile to switchboard with different assemblies of apparatus and in addition a balance of thermal gains against costs. The object of such a study is to produce a kilowatt-hour at the switchboard at a minimum station cost with reliability, station operating conditions and ease of operation predominate elements.

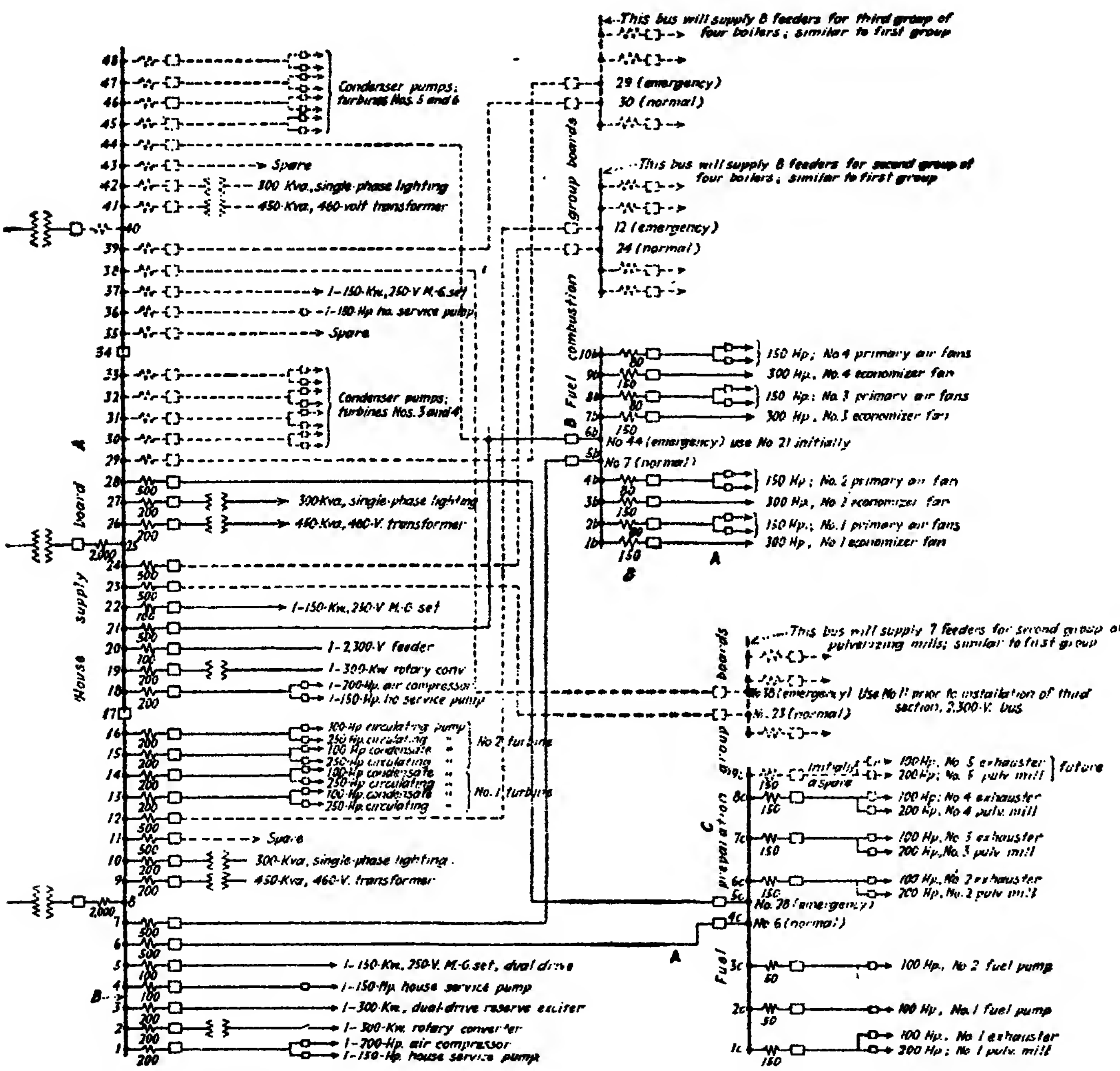

FIG. 81.—Auxiliary electrical supply for the Avon station of the Cleveland Electric Illuminating Company.

Needless to say, such a computation is laborious and long and requires definite data to be accurate. But if a station is to be used many years and is to cost millions of dollars it is good business as well as good engineering to make a complete economic heat-balance analysis. Two representative and typical analyses will be found in the 1925 *Report* of the Prime Movers Committee of the National Electric Lighting Association. One is by Linn Helander and the other by F. H. Rosencrants.

CHAPTER VII

BOILER-ROOM EQUIPMENT AND LAYOUT

The boiler room of a power station should be designed to operate continuously at high efficiency in order to produce a maximum amount of steam from a minimum amount of fuel. In this part of the station there occurs the greatest variation in possible economic operating conditions and one of the least efficient energy transfer processes, so that extreme care in design is warranted. Also the boiler room has inherent complexities in control and equipment assembly which make it advisable to plan the installation so that it will be automatic in operation, easy to maintain and pleasant for workmen.

A base-load station which operates at or near full load continuously justifies a higher investment in equipment to secure maximum thermal efficiency and maximum automatic operation than a station which operates at a low-load factor or as a standby station for hydro plants. An analysis must be made for a specific station to determine the balance point between investment to secure high thermal efficiency and exact operation and the cost of fuel used. Load factor and local operating conditions are the important elements in arriving at a decision.

A well-designed boiler room should be clean, safe, well ventilated and well lighted; it should have ample clearances for the movement of operators and the repair and replacement of equipment and the auxiliaries should be selected to give reliable operation under all conditions of operation. The fuel should be handled economically and quickly and the piping should be designed to secure the shortest possible paths for steam and water consistent with flexibility and safety. Valves should be chosen carefully for each service and a minimum number should be used. Automatic and remote controls for valves and major auxiliaries is favored, so that operators under normal and emergency conditions can operate the station with a minimum of movement and a maximum of safety. Fuel storage inside the station should be a minimum consistent with reserve requirements and the fuel

should be handled quickly in enclosed containers to eliminate dirt, gases or the possibility of explosions.

The larger power stations utilize the unit boiler principle in the boiler plant installation. One, two or three boilers are used with each prime mover and the auxiliaries are installed and operated as a part of the boiler-turbo-generator unit plan. Reserve connections to other boilers, reserve auxiliaries and other second or third lines of defense to give service to the unit plant in emergencies may or may not be warranted in a given station. Boilers are being built in very large sizes and the trend is toward a one-boiler-per-turbine type of installation. Also there is a tendency to combine in one unit and in one location the boiler-turbine generating unit since this eliminates piping, fire walls and building volume. The whole art of the boiler room is in a state of flux and the future boiler plant is difficult to predict.

The combustion chamber is the most rapidly changing part of boiler plant design. With the increase in size of boilers there was a corresponding increase in the furnace volume and a consequent difficulty in the control of furnace temperature, fuel feed and in the use of refractories. The advent of pulverized fuel was followed by difficulties in the use in the older type of furnace and stimulated developments in the furnace. Air-cooled side walls and water screens were next used in furnaces and then came still more radical innovations equivalent to burning fuel in a furnace entirely surrounded by steaming surface which might or might not be protected by refractories. Recent improvements in stokers have brought about greater possibilities for their use under boilers of large rating and the use of highly turbulent combustion of pulverized fuel in some installations affords very promising results. Thus the tendency today is toward a very high rate of combustion in a smaller furnace volume, the elimination of refractories and arches of the older type installations, the use of heated combustion air from flue-gas air heaters and the better design of boilers to get a better distribution of steaming surface and a better utilization of the heat in the furnace.

Boiler-room Layouts.—Many arrangements of boiler rooms can be used. Figure 82 shows a type of boiler-room layout which involves the use of multiple firing aisles. Normally, each group of two boilers supplies a prime mover, but a common header is available for transfer use if occasion demands. A common firing-aisle type of plant using a compound turbine

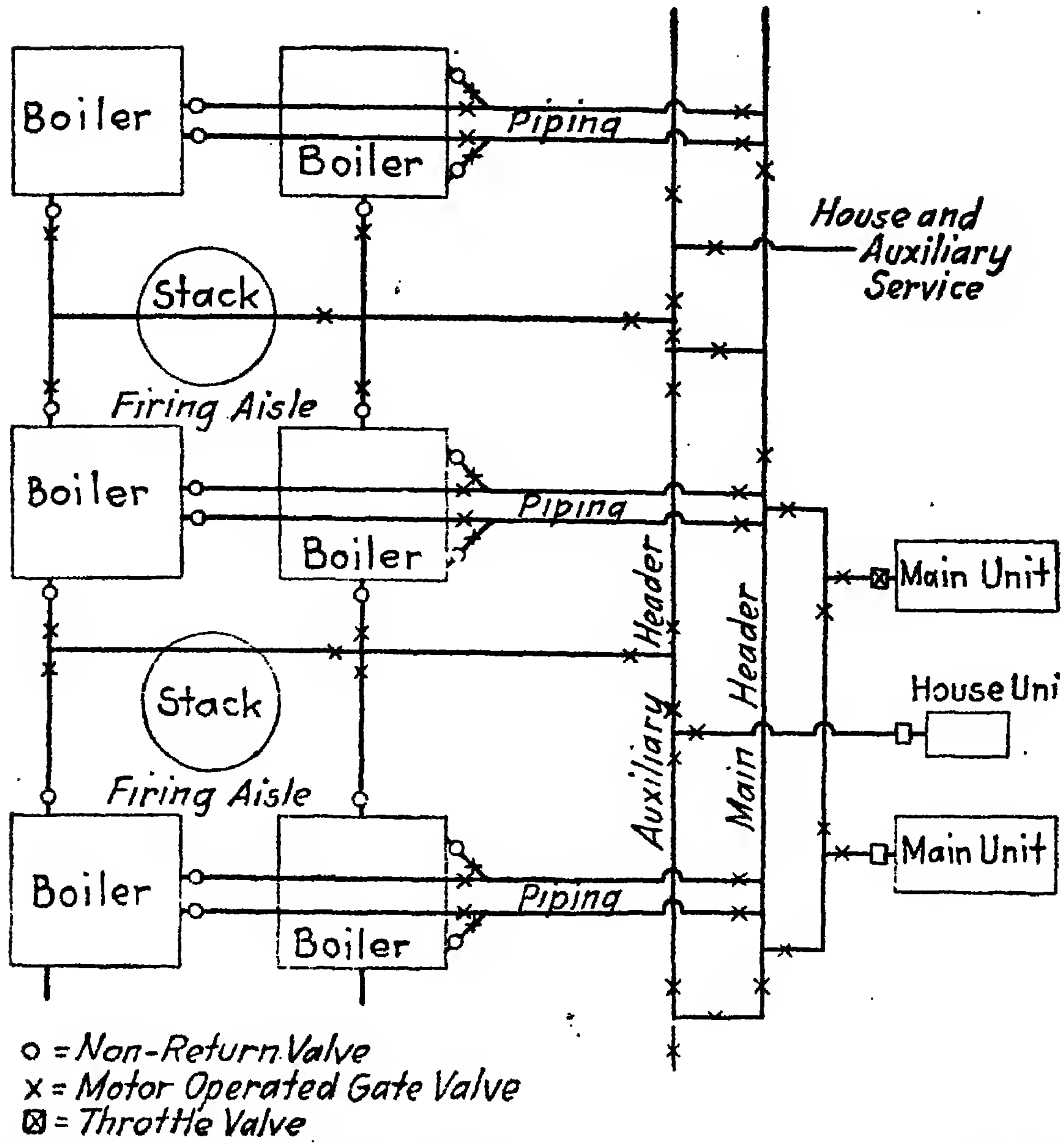

FIG. 82a.—Type of station layout for use with multiple firing aisles.

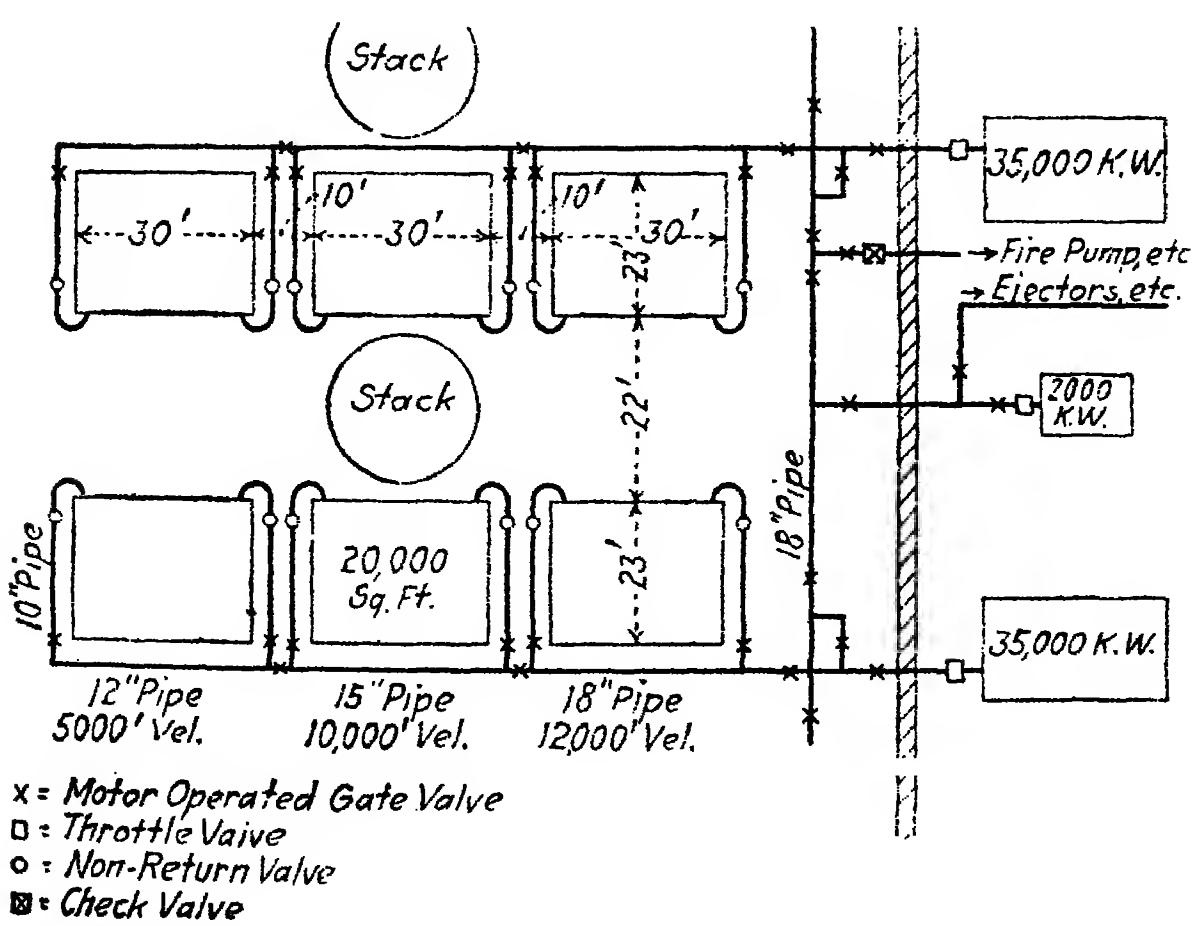

FIG. 82b.—Type of station and valve layout for unit operation and using one firing aisle.

with three boilers per unit and per stack is shown in Fig. 82. The use of one firing aisle requires a minimum number of coal weighing larries. The coal-feeding, storage and handling system can be made simple and the piping layout is less complicated. But the station location, the type of fuel used, the fuel-burning system installed, the size of units, draft and flue designs and requirements, lighting requirements and other elements are so variable that no one layout may be accepted as best for all stations. Several modern station boiler-plant layouts are shown to illustrate the variety of arrangements in use.

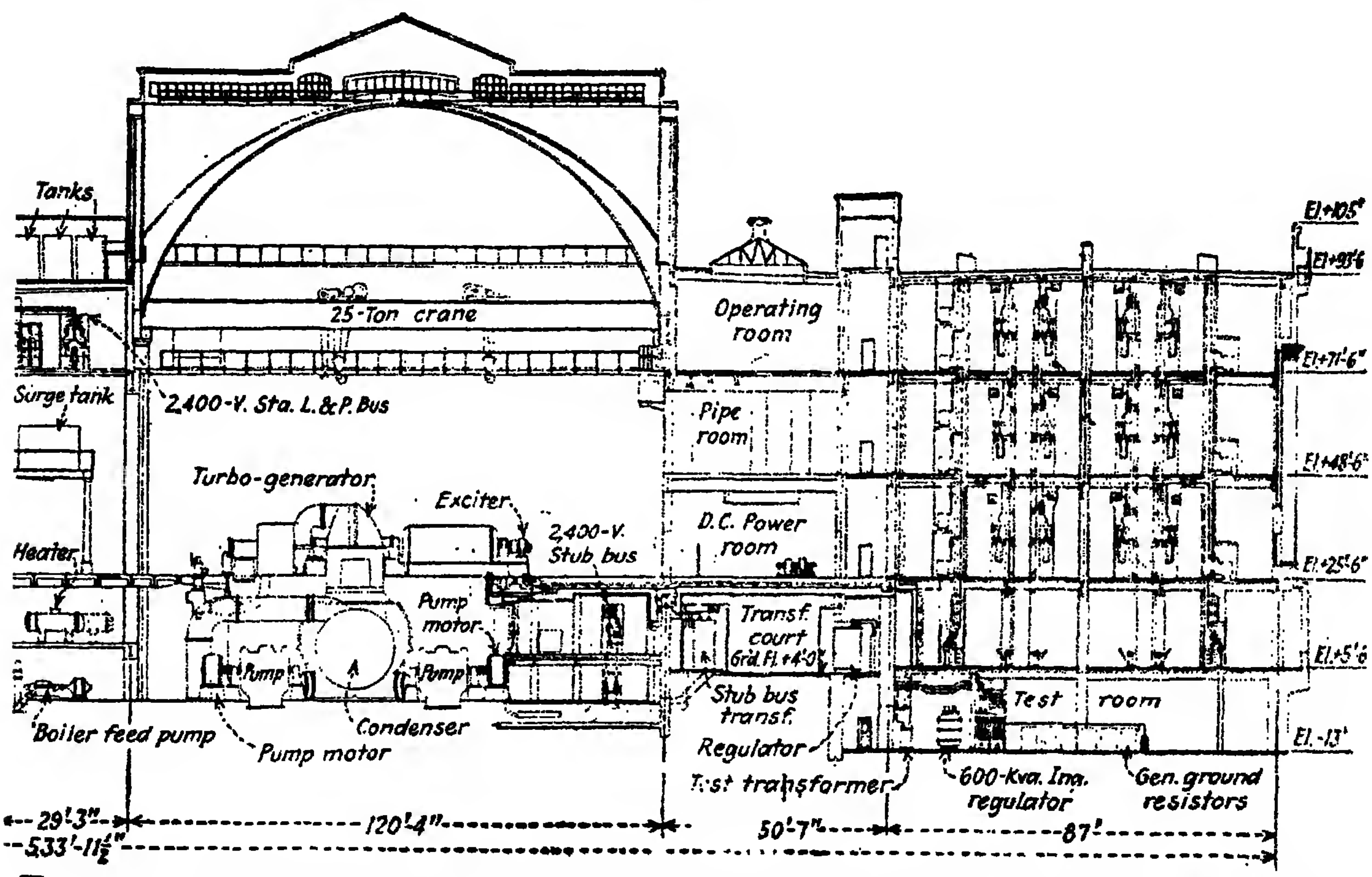

FIG. 83.—Cross-section of the turbine room and switch house of the 600,000-kw. Richmond station of the Philadelphia Electric Company.

It has been customary to interpose a fire wall between the boiler room and the turbine room but recent tendencies in design raise the question as to whether it would not be better to separate different boiler-turbo-generator units in a station by a fire wall rather than attempt to separate the boilers from the prime movers. Stations with large units which operate as independent power stations under one roof under normal conditions would be safer with a better separation of complete units. Under any condition of failure or accident to either boiler, turbine or generator a station unit is out of service and a fire-wall separation between the faulty unit and adjacent units would limit damage in the event of a bad mechanical failure, a fire, or the escape of steam. In addition, the tendency to bring the boiler and prime mover

closer to each other introduces another influence which presages the ultimate elimination or modification of the fire walls now used.

The fuel to be burned in a station, the rating of a station and the station load factor are decisive elements in the selection of the boiler units, the boiler-room auxiliaries and the method of fuel burning. Coals vary widely in their B.t.u. content and in their characteristics when burned under boilers and the use of stokers or pulverized-fuel-burning equipments is determined by this fact and relative costs rather than by any superiority in efficiency to be obtained by one or the other when burned properly. A study should be made of available fuels, their characteristics for burning under boilers with different equipments available, and of costs involved in installation and operation. This will determine largely the choice of a certain type of stoker or pulverized-fuel-burning installation. A coal preparation house or department is a necessary part of the bin system of pulverized-fuel installation and this item is an influential element in relative investment costs.

Boilers should be large and adapted to the operations of the station. Fully insulated boilers should be used and they should be installed to get a minimum cost for maintenance, especially in the furnaces. The furnace temperature is a limiting factor in the use of refractories and the steam temperature should be held to close limits by a properly designed and installed superheater. Practice calls for the operation of furnaces and of steam at a temperature very near the upper limit allowable to avoid mechanical failure of the materials used in a boiler and furnace. Thus accurate design and sensitive control under operating conditions are essential elements to consider.

Draft systems are usually both forced and induced in order to secure the high combustion rates desirable in the large boiler installations. Feed-water treatment is also desirable in the expensive large stations if there is any chance that impure feed water may keep a unit out of service and thus prevent any earnings being made on a large investment.

Automatic combustion control is a recent innovation in large stations and several successful systems have been developed. In principle, they are best based on a change in steam pressure causing a response in steam generation which is quick and which operates without causing hunting or oscillations. High efficiency

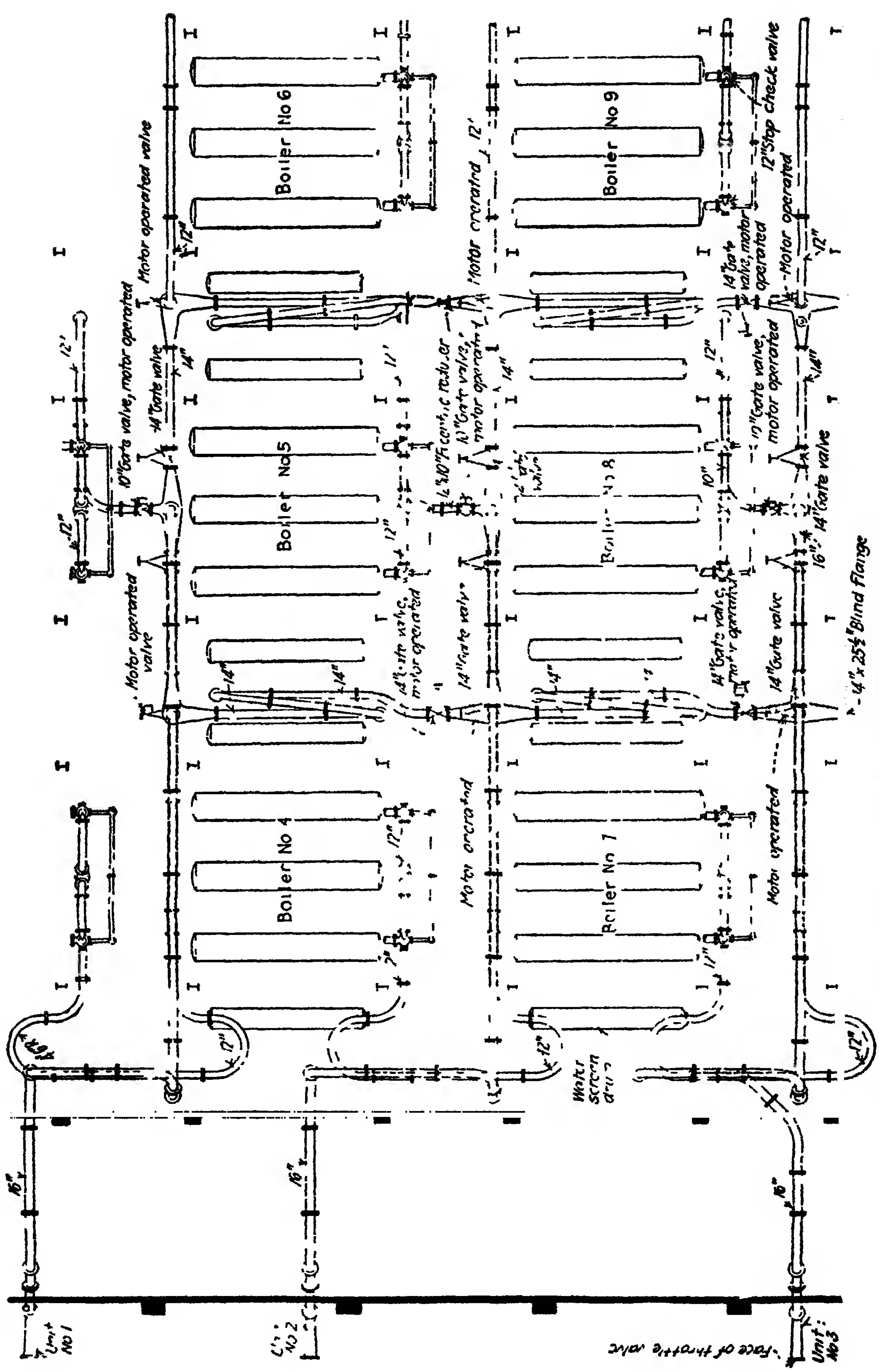

FIG. 84a.—Plan of main superheated steam piping in the Trenton Channel Station of the Detroit Edison Company.

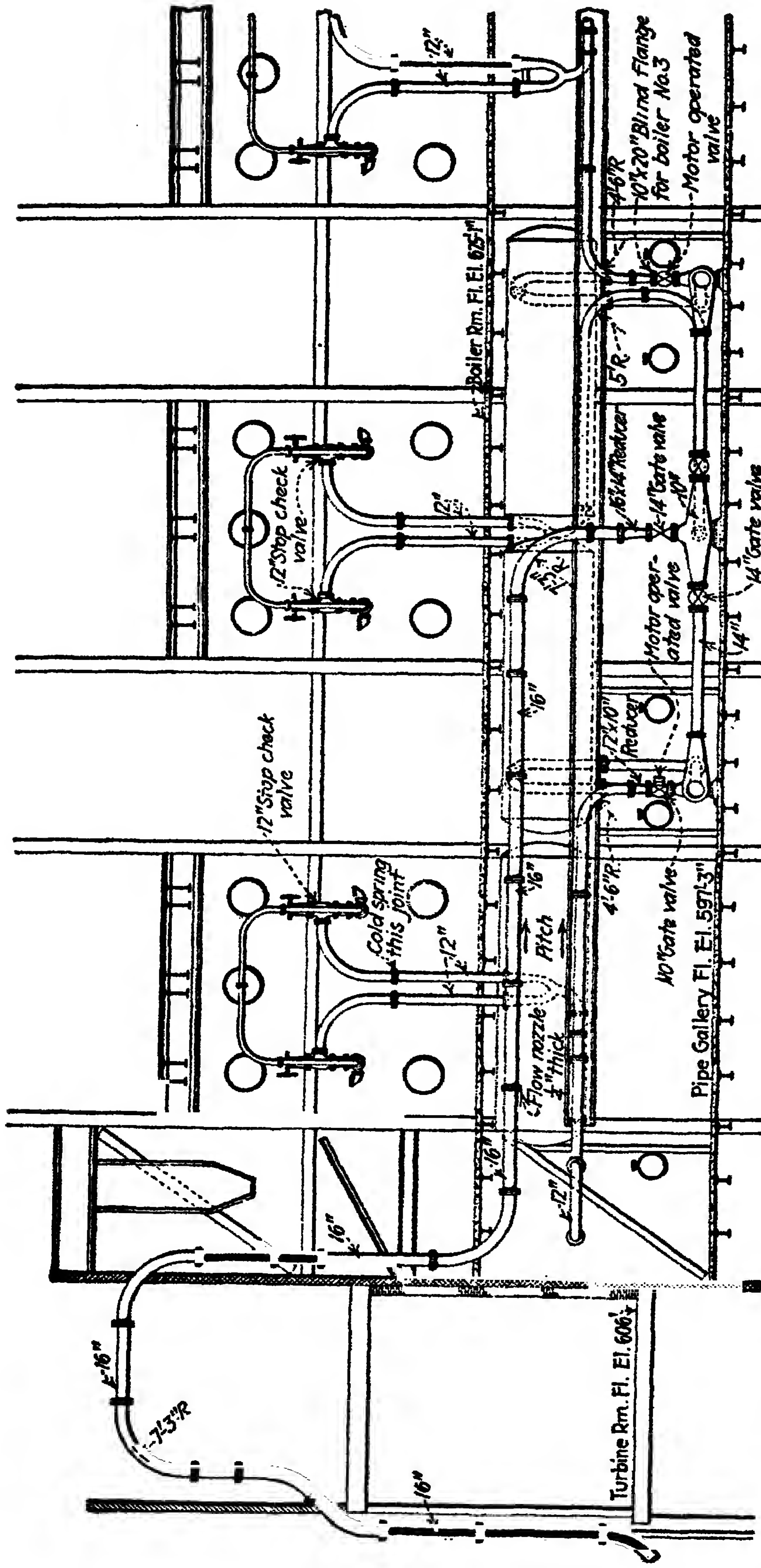

FIG. 84a.—Elevation of main superheated steam piping in Trenton Channel Station of the Detroit Edison Company. (*Continued.*)

must be obtained at all loads and any part of the automatic equipment should be readily repaired or thrown to hand control if necessary.

Coal supply must be regulated to meet the steam demands, the volume of air must be regulated to burn the coal with a certain predetermined value of CO_2, the speed of the fans must change to give the proper air pressures and, when pulverized fuel is used, individual coal-feeder motors must be regulated. Thus automatic controls involve a number of operations and must be very reliable. The fact that several manufacturers have successful installations shows that the problem has been solved and experience has proved that higher day-to-day efficiency can be

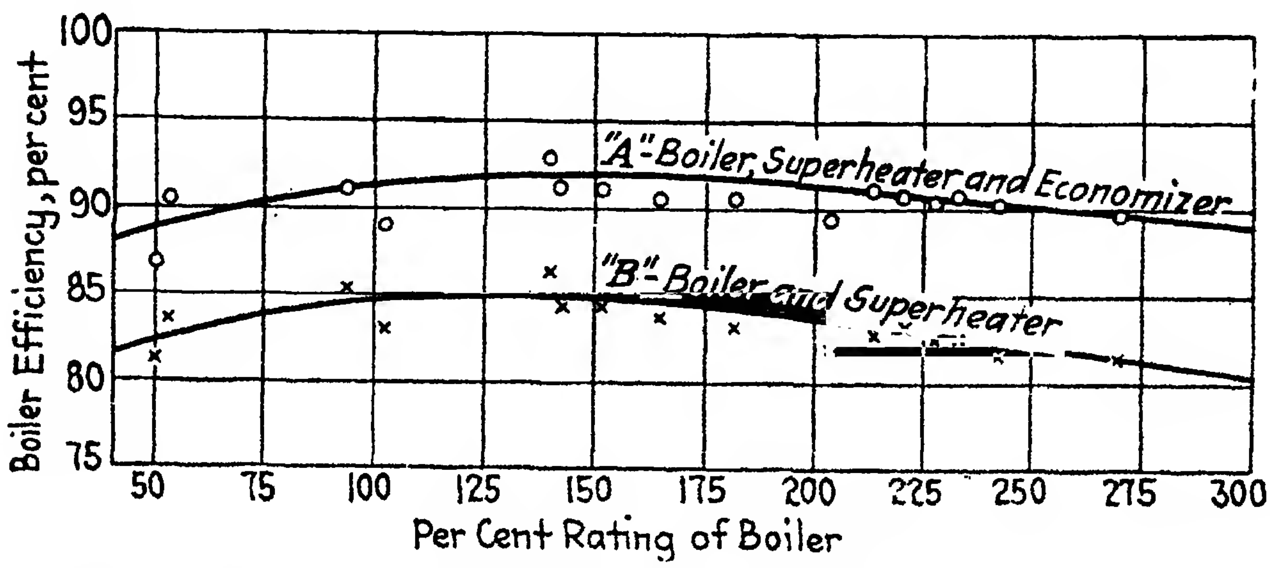

FIG. 85.—Test efficiency of 30,600-sq. ft. boiler at the Lake Shore station of the Cleveland Electric Illuminating Company. *A*. Boiler, superheater and economizer. *B*. Boiler and superheater.

obtained with automatic operation of boiler plants than when hand control is used.

The centralization of control in a boiler-control room is sought usually but provision should be made for control at each boiler if necessary.

Boiler Types and Ratings.—The pressures, temperatures, steaming conditions and designs used in modern boiler plants differ very widely, and even boiler ratings have come to mean but little. To compare boiler performance it is necessary to reduce conditions to an equivalent basis, which is usually referred to as equivalent evaporation from a feed-water temperature of 212° into dry saturated steam at the same temperature. As usually given, a boiler rating on this basis in terms of pounds of steam per hour is:

$$\text{Equivalent evaporation} = \frac{H - q \times \text{pounds of water fed per hour}}{971.7}.$$

Boiler ratings are, however, given in terms of: (1) the pounds of steam produced per hour, (2) the number of boiler horsepower based on the evaporation of 34.5 lb. of water per hour and at 212°F. and (3) the square feet of heating surface. On a unit basis

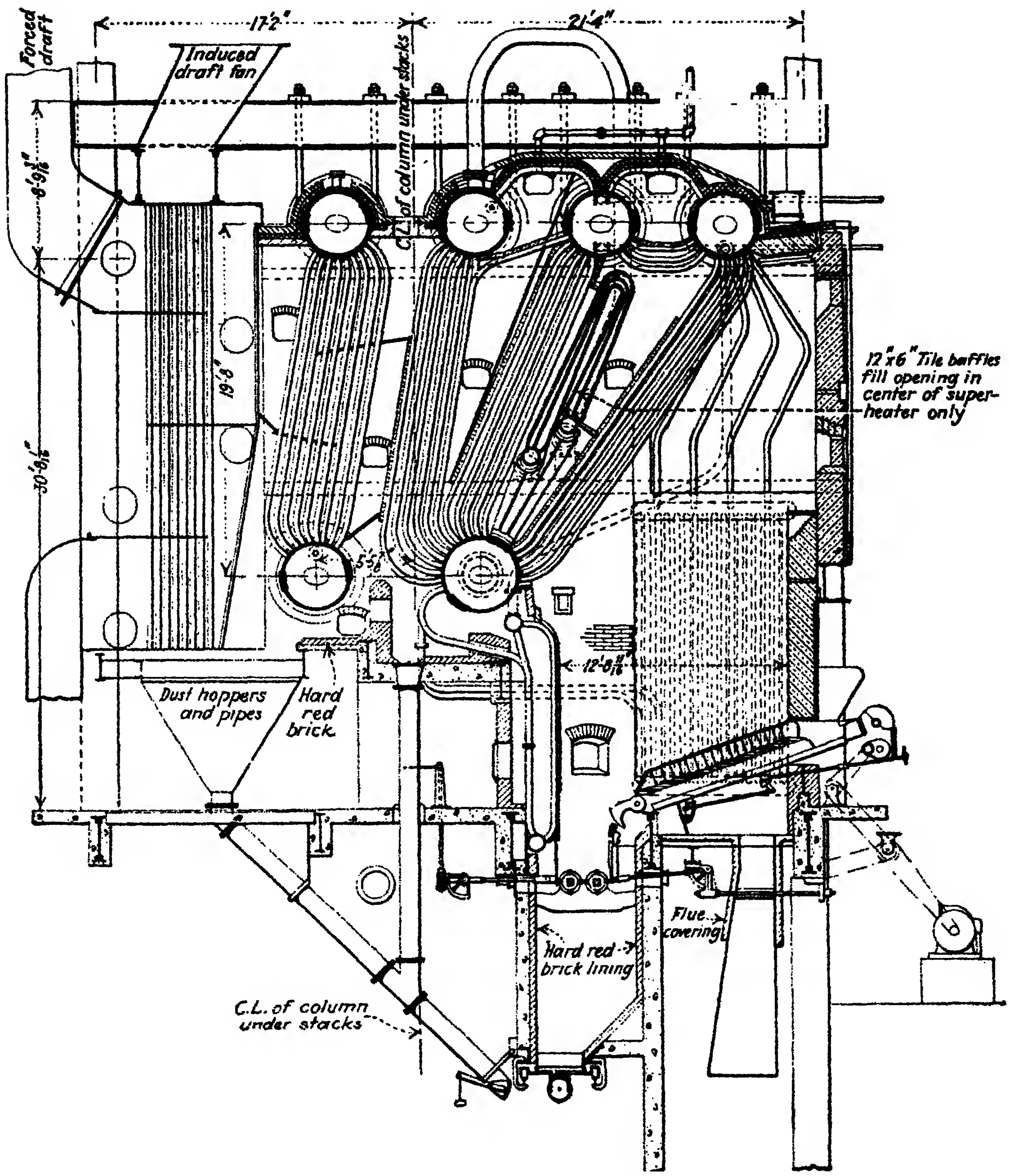

FIG. 85.—Cross-section of boiler installation in Richmond station of the Philadelphia Electric Company.

the efficiency of a boiler is measured by the number of pounds of water evaporated per pound of combustible based on 212°F.; the rapidity of steam production is given in terms of the equivalent evaporation per square foot of heating surface; and the rate of fuel consumption is measured by the number of pounds of coal

burned per square foot of grate surface per hour or by the coal burned per cubic foot of combustion chamber volume per hour.

Many of the ratings used are somewhat objectionable from the standpoint of comparing boiler performances, particularly the boiler horsepower rating and the square foot of heating surface rating. It is generally best to use steaming ratings based on total equivalent evaporation per hour. The use of economizers, air heaters, superheaters and other accessory apparatus as

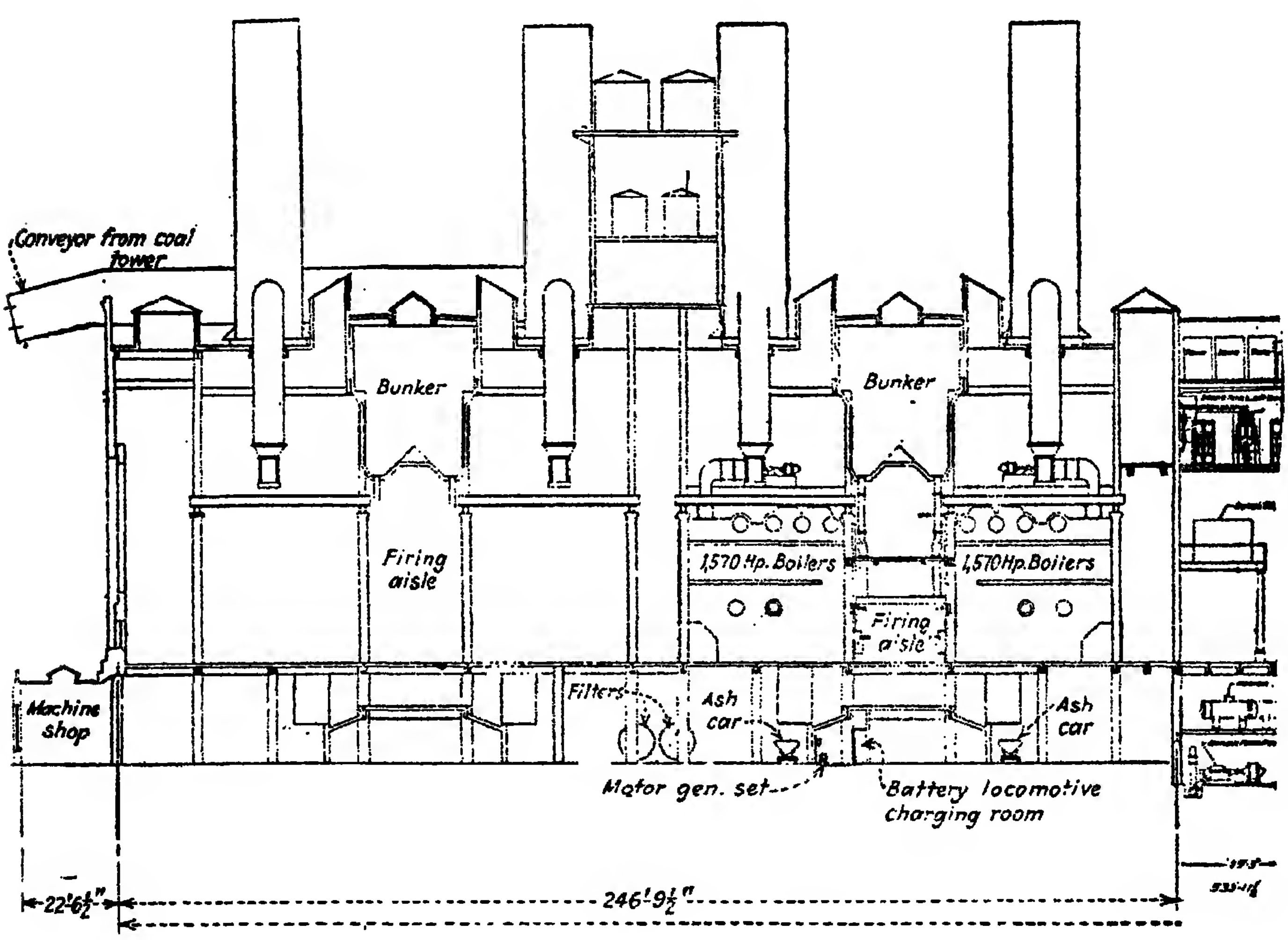

FIG. 86.—Cross-section of the boiler room of the Richmond station of the Philadelphia Electric Company showing general arrangements. 600,000-kw. rating.

integral parts of the boiler make it necessary to be very specific in comparing boiler ratings and the great variation in furnace sizes, types of fuel used and combustion methods make it very difficult to compare the performances of boilers in different stations.

From an operating standpoint, boilers should be compared on the basis of B.t.u. per kilowatt-hour, their steaming rate per hour, their speed in picking up load and their ability to carry overload. The relative merits of the different types of boilers and details of their design are recorded in handbooks. Personal opinions of engineers, costs, operating conditions as to temperature and pressures, type of plant, size of plant and fuels used are very

influential elements in determining the type of boiler to select. Nearly every type is used with the horizontal-return-tube and vertical Stirling types predominating in the large stations.

The distribution of heating surface, the baffling, the furnace design, the location of economizers and superheaters and the type of other equipment used are determined by patent considerations,

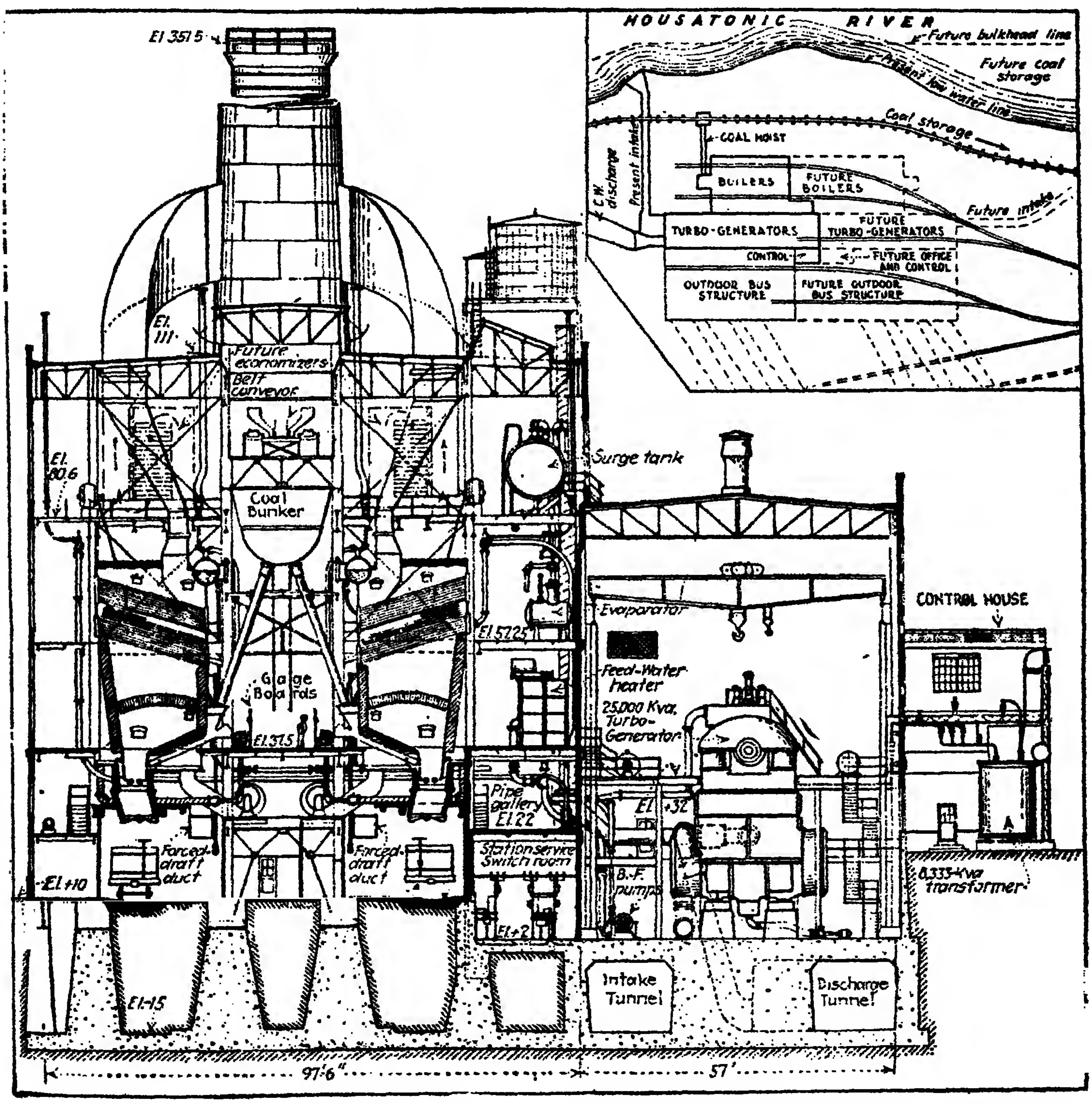

FIG. 87.—Cross-section of station and property plan for the Devon station of the Connecticut Light and Power Company. 200,000-kw. ultimate rating.

by empirical rules, by operating experiences or by economic factors determined very largely by conditions peculiar to each installation. The theory of combustion, heat transfer, water and steam mixture, gas flow and other variables in boiler design have not been ascertained accurately enough to apply without assumptions or modifications to boiler plant design on a strictly quantitative basis.

TABLE XXIII.—CHARACTERISTICS OF BOILER INSTALLATIONS IN AMERICAN STATIONS

Name of station	Type of boiler	Diameter and length of tubes	Number of boilers	Tubes, height	Tubes, width	Heating surface of boiler, square feet	Heating surface of S. H., square feet	Heating surface of economy, square feet	Type of stoker	Number of stoker retorts	Number of tuyères per retort	Furnace volume, cubic feet	Steam pressure gage, pounds	Steam temperature degrees Fahrenheit
Barbadoes Island, Bridgeport, Pa.	Springfield cross-drum Interdeck, S.H.	3 in. O.D. No. 10 B.w.g. 20 ft. 0 in.	3	24	48	16,800	S.H. Co. 2,025	....	Single-ended Westinghouse	12	27	5,057	305	625
Colfax station extension, Cheswick, Pa.	B. & W. cross-drum Interdeck, S.H.	4 in. O.D. No. 8 B.w.g. 20 ft. 0 in.	6	20	51	22,914	B. & W. 2,919	a	Single-ended Westinghouse	17	21	6,720	275	
Cahokia station, E. St. Louis, Ill.	B. & W. cross-drum Interdeck, S.H.	4 ft. O.D. No. 7 B.w.g. 20 ft. 0 in.	8	20	38	18,010	B. & W. 4,070	....	Lopulco pulverized-fuel burners; 10 burners per boiler	..	....	12,850	350	686
Hell Gate extension, New York.	Springfield cross-drum	20 ft. 0 in.	3	18	54	15,500	Foster 7,430	Foster 13,824	Single-ended Taylor	14	33	8,000	300	622
Lake Shore Station 2, Cleveland, O.	Double-ended Stirling	3¼ in. O.D. 19 ft. 1¼ in.	4	16	55	30,600	B. & W. 6,550	Foster 22,464	Lopulco pulverized-fuel burners; 16 burners per boiler	..	....	29,150	250	685
Marysville station, Marysville, Mich.	Double-ended Stirling	3¼ in. O.D. No. 9 B.w.g. 21 ft. 4 in.	4	15	53	28,212 29,100	B. & W. 3,168	....	Double-ended Taylor	28	22	9,727	300	700
Devon station, Devon, Conn.	Springfield cross-drum interdeck, S.H.	3 in. O.D. No. 10 B.w.g. 20 ft. 0 in.	6	24	48	16,800	Superheater Co. 1,980	....	Single-ended Westinghouse	12	27	5,696	320	625
Hudson Avenue station, Brooklyn, N. Y.	B. & W. cross-drum interdeck, S.H.	20 ft. 0 in.	8	20	42	19,650	B. & W. 2,350		Single ended: 6 Westinghouse; 2 Frederick	6–14 2–14	27 29	7,280	300	614
Springdale station, Springdale, Pa.	B. & W. cross-drum interdeck, S.H.	4 in. O.D. No. 7 B.w.g. 20 ft. 0 in.	8	16	42	16,396	3,320	B. & W.	Single-ended Westinghouse	14	27	6,736	350	700

Tennessee Electric Power Co., Guild, Tenn.	B. & W. cross-drum	4 in. O.D. No. 6 B.w.g. 20 ft. 0 in.	3	18	25	10,752	B. & W. 2,000	Green 7,470[b]	Single-ended Riley	8	Furnace depth, 14 ft. 10 in.	3,760	375	727
Trenton Channel station, Trenton Channel, Mich.	Double-ended Stirling	3¼ in. O.D. No. 6 B.w.g. 21 ft. 4 in.	8	15	53	29,100 plus 1,231 in water screen	B. & W. 5,750	B. & W. 18,984	Lopulco pulverized-fuel burners; 16 burners per boiler	..	....	25,140	411	700
Valmont station, Valmont, Colo.	Bigelow-Hornsby	....	9 units 4 wide	..	..	10,730	Foster 6,288	Bigelow-Hornsby Integral 2,590	Lopuloco pulverized fuel burners; 8 burners per boiler	..	....	8,350	375	642
Edgar station, Weymouth, Mass.	B. & W. cross-drum	4 in. O.D., 20 ft. 0 in.	3	17	48	19,743	B. & W. 2,938	2 B. & W. 11,091 1 Foster 12,096	Single-ended Taylor	16	25	9,000	375	700

[a] In the Colfax station in connection with one 22,914-sq. ft. boiler there is installed a 11,200-sq. ft. plate-type air heater (Combustion Engineering Corporation).

[b] In the Tennessee Electrical power plant there is a 5,504-sq. ft. horizontal-tube airheater (Green Fuel Economy Company) installed in connection with each 10,752-sq. ft. boiler.

There is no definite limit to the capacity of a boiler to absorb heat except the capacity of the combustion chamber to burn fuel and the economic limitations involved in operating the station at low efficiency. The efficiency of a boiler is comparatively flat over a wide range but reduces to zero at no load and drops rapidly when the boiler is forced beyond a specified maximum rating. The permissible variation in draft, the degree of water circulation and the rate of fuel feeding are practical limitations in forcing boilers.

To show the differences in practice, Tables XXIII and XXIV are presented covering boilers of about the same size operating under different conditions.

TABLE XXIV.—CHARACTERISTICS OF MODERN BOILER PLANTS

Type of boiler	Calumet, B. & W.	Seward, B. & W.	Hell Gate, Springfield	So. Meadow, Bigelow Hornsby	Delaware, Stirling Class M
Diameter and length of tube	4 in. by 20 ft.	4 in.	4 in. by 20 ft.	......	3½ in.
Heating surface, square feet	15,089	15,964	18,900	13,920	15,081
Steam pressure	350	280	250	275	265
Steam temperature	685	596	606	640	630
Superheater surface, square feet	4,000	5,000	2,135	6,250	1,790
Type stoker	Coxe	Taylor	Taylor	Riley	Taylor
Grate area, square feet	376	265	472	286	322
Furnace volume, cubic feet	6,700	5,194	8,000	6,370	7,200
Economizer surface, square feet	9,600	None	None	2,750	3,950

In Table XXV is given some information on different classes of boilers prepared in response to an invitation for bids by the city of Detroit.

Accompanying illustrations show typical boiler sections in modern stations.

Economizers.—Economizers became of increasing advantage as the cost of fuel increased and most stations installed them until the advent recently of the air heater. For many years only cast-iron tubes were used in economizers because of the corrosion occurring in the steel-tube type, but with the use of higher pressures and temperatures, distilled boiler feed water and the deaëration of feed water, steel-tube or a steel-tube with cast-iron-covering type of economizers have been used.

The economizer may or may not be integral with the boiler. In the integral type it has been found difficult to keep joints tight and to clean the tubes conveniently while the external type of economizer installation is expensive and air leakage may occur more readily. In the very high-pressure installations the economizer may operate at a lower pressure than the boiler.

The selection of economizers requires a study and analysis involving the temperature at which the feed water should leave

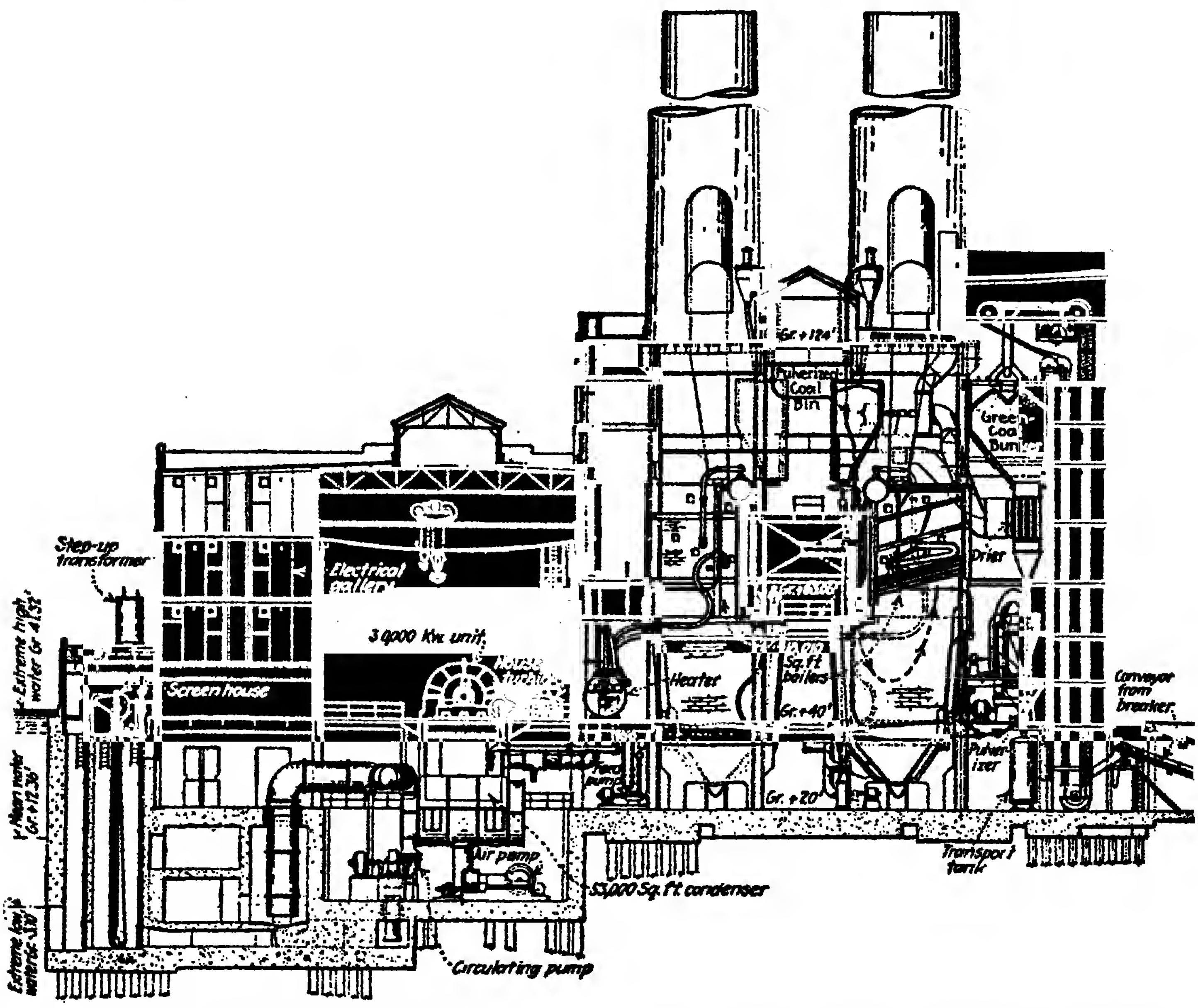

FIG. 88.—Relative position of equipment in the Cahokia station of Union Electric Light and Power Company. Foundation expense was a ruling factor in its design.

the bleeder heaters and enter the economizers, the most advantageous divisions of heating surface between the boiler and the economizer and relative merits and costs of other methods of feed heating, such as air heaters or extraction steam heaters.

The turbine units operate with greatest economy when feed heating is done with extracted steam but the boiler operates at greatest efficiency when feed heating is done in an economizer, air heater or both. The best overall condition of station efficiency will therefore be obtained by a compromise. As a rule,

TABLE XXV.—SCHEDULE OF BOILER BIDS FOR DETROIT MUNICIPAL PLANT[1]

Bidder	Babcock & Wilcox Co.		D. Connelly Boiler Co.		D. Connelly Boiler Co.		Heine Boiler Co.		Geo. T. Ladd Co.		Wickes Boiler Co.		Springfield Boiler	
Address	New York		Cleveland		Cleveland		St. Louis		Pittsburgh		Saginaw, Mich.		Springfield, Ill.	
Price—six boilers	$279,438.00		$204,900.00		$195,900.00		$290,200.00		$164,500.00		$203,051.00		$206,000.00	
Price—eight boilers	372,584.00		273,200.00		261,200.00		377,800.00		215,100.00		270,382.00		273,000.00	
				Per cent tolerance		Per cent tolerance		Per cent tolerance		Per cent tolerance		Per cent tolerance		Per cent tolerance
Delivery time	First boiler 21 weeks, one boiler per month thereafter		28 weeks	20	28 weeks	20	52 weeks	10	32 weeks	10	30 weeks	20	22 weeks	20
Erection time	Six boilers within 40 weeks from delivery of first boiler		36 weeks	20	36 weeks	20	68 weeks	10	4 weeks	10	8 weeks	20	9 weeks	50
		Per cent tolerance												
Net weight per boiler, pounds	297,000	......	280,000	10	....	......	380,000	......	210,000	5	230,000	10	270,000	5
Water-holding capacity, cubic feet	1,761	......	2,260	5	....	......	925	......	1,700	1	1,720	5	1,314	5
Maximum moisture in steam at nozzle, evaporation 110,000 lb. per hour	1 %	......	1 %	15	1 %	15	0.75 %	......	1 %	None	1.5 %	30	None	None

	Pounds per hour															
Draft loss (inches of water) through boiler when weight of flue gas is	85,000	0.17 in.	10	0.10 %	15	0.10 %	15	0.14 %	5	0.25 %	2.5	0.20 %	15	0.20 %	25
	173,000	0.84 in.	10	0.43 %	10	0.43 %	10	0.60 %	5	0.55 %	2.5	0.40 %	15	0.55 %	36.4
	260,000	1.75 in.	10	1.43 %	5	1.43 %	5	1.60 %	5	1.20 %	2.5	0.65 %	15	1.25 %	28
Flue-gas temperature at outlet when furnace temperature is 2400° and weight flue gas is	85,000	480°F.	10	460°	5	460°	5	509°	5	490°	2.5	485°	10	475°	2.1
	173,000	570°F.	10	535°	5	535°	5	539°	5	550°	2.5	520°	10	530°	4.7
	260,000	675°F.	15	640°	5	640°	5	632°	5	680°	2.5	575°	10	600°	6.6
Efficiency boiler and superheater when furnace temperature is 2400° and weight of flue gas is	85,000	76.7 %	0.5	77°	2	77 %	2	77 %	3	78.8 %	2.5	92.2 %	2.5	79.5 %	1
	173,000	74.5 %	0.5	74.5°	2	74.5 %	2	74.3 %	3	75.2 %	2.5	90.3 %	2.5	76.5 %	1
	260,000	70.5 %	0.5	67.5°	3	67.5 %	3	71.8 %	3	71.5 %	2.5	87.3 %	2.5	73.5 %	1
Type boiler		Horizontal water tube, one cross-drum		Horizontal water tube, two cross-drums		Horizontal water tube, one cross-drum		Horizontal water tube, one cross-drum		Vertical water tube, three cross-drums		Horizontal water tube, one cross-drum		Horizontal water tube, one cross-drum	
Type header and material		sectional, forged steel		sectional, cast steel		sectional, cast steel		sectional, cast steel		....		box, steel plate		sectional, cast steel	
Heating surface, square feet		15,920		15,956		....		15,740		15,300		15,630		15,800	
Size drum, inches		54		44		54		54		Two 42 in. One 48 in.		54		54	
Thickness drum, inches		1.125		1		....		10,625		42 in.-1.5 48 in.-1.6875		....		1.125	
Size tubes, inches		4		4		4		3.5		3.25		4		3	
Gage tubes, b.w.g.		No. 7		No. 7		No. 7		No. 8		No. 9		....		No. 9	

[1] *Electrical World*, Aug. 25, 1923.

feed heating will be done with extracted steam to secure a temperature of at least 220°, as this temperature prohibits any corrosion in the economizers, requires no superheat in the exhaust steam and permits adequate deaëration of the feed water. Then a study should be made to determine whether the air heater or economizer should be used.

The use of a counterflow economizer surface increases boiler and economizer efficiencies but costs vary in a way to force a

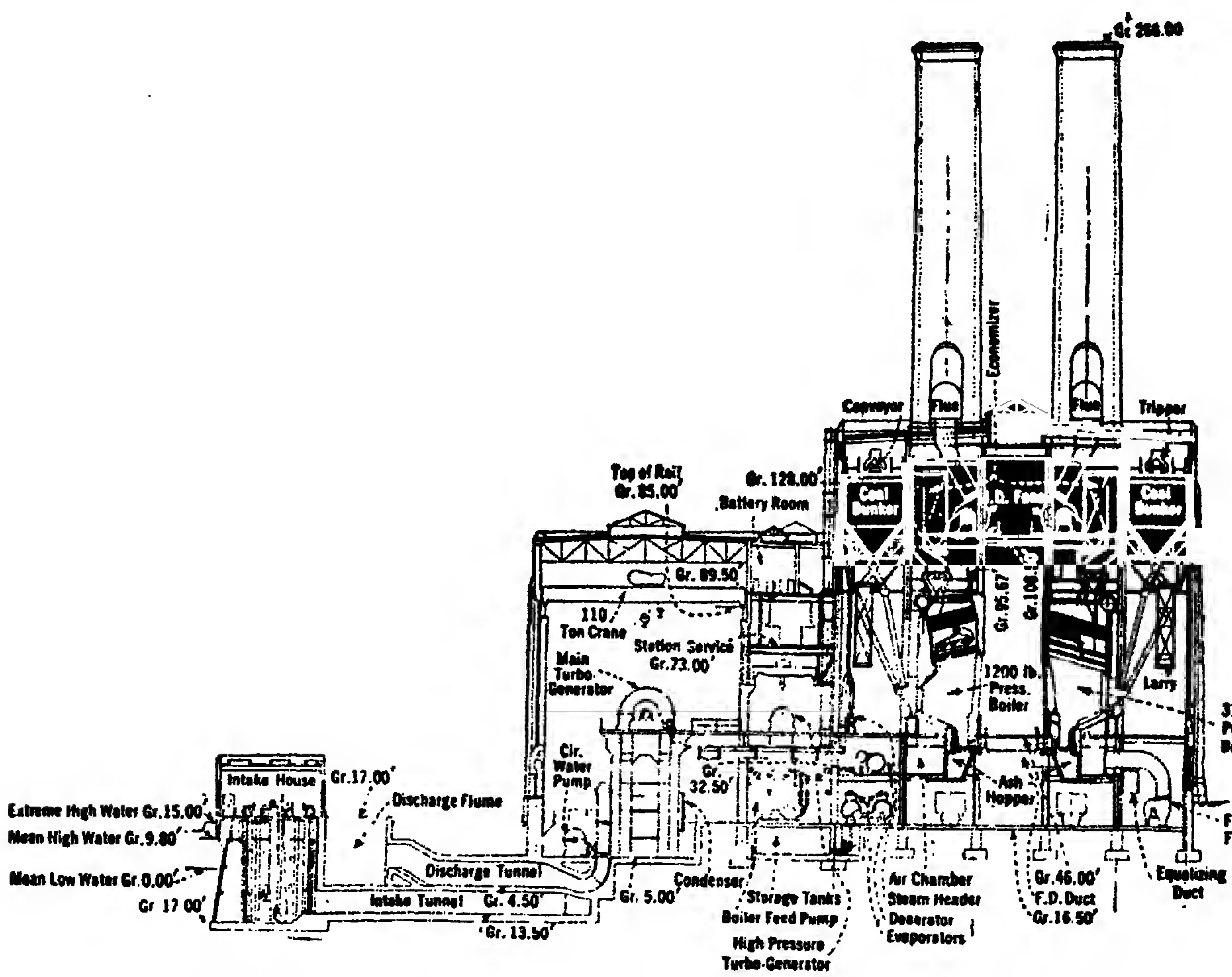

Fig. 89.—Cross-section of the Edgar station of the Edison Electric Illuminating Company of Boston.

compromise and the arrangement of boiler surface also has a practical bearing on the solution of the problem. With the increased use of air heaters and extraction steam-feed heaters it is probable that economizers will be restricted still more as to heating surface or entirely eliminated. The data given in Table XXVI are the results of tests on a boiler, stoker and economizer installation at the Essex Station of the Public Service Electric and Gas Company.

The boiler was a Babcock & Wilcox cross-drum type, forty-four tubes wide, fourteen tubes high, having a 60-in. diameter drum and containing 12,781 sq. ft. of heating surface, having a

TABLE XXVI.—DATA FROM TEST ON BOILER STOKER AND ECONOMIZER[1]

	Test Nos.				
	1	2	3	4	5
Water per hour	56,635	69,243	78,446	100,154	106,174
Dry coal per hour	6,040	7,589	8,428	11,246	12,466
B.t.u. per pound dry coal	13,221	13,339	13,541	13,976	14,036
Boiler output, per cent rating	151.2	183.9	209.4	269.1	283.7
Economizer:					
Temperature of gases entering, degrees	446	429	424	452	446
Temperature of gases leaving, degrees	240	282	291	323	326
Temperature of water entering degrees	102.3	107	108.9	109.4	110.8
Temperature of water leaving, degrees	181.9	194.7	196.7	206.6	215.8
Temperature drop in gases	206	147	133	129	120
Temperature rise in water	79.6	87.7	87.8	97.2	105.0
Per cent CO_2	9.2	9.4	7.8	7.6	7.2
Per cent CO	0.2	0.0	0.0	0.0	0.0
Per cent O_2	9.3	9.3	10.9	8.3	11.0
Pounds economizer gas per hour	123,300	154,000	206,500	295,000	345,000
Calculated average gas per hour	860	1,075	1,445	2,135	2,500
Draft loss through economizer, inches of water	0.08	0.33	0.57	1.12	1.29
Coefficient of heat transfer	2.9	3.82	4.32	5.46	6.17

[1] Prime Movers Committee, N.E.L.A., 1923.

	Square Feet
Boiler, heating surface	12,781
Economizer, heating surface	7,750
Superheater, heating surface	3,160
Free area through economizer	49

Taylor underfeed stoker with fifteen retorts, designed to develop 350 per cent of normal boiler rating for 2 hr.

The boiler had a B. & W. superheater of 3,160-sq. ft. heating surface and a Sturtevant Economizer of 7,750 sq. ft. of surface.

The weight of gases through the economizer was estimated and the velocity tabulated is the mean of the calculated entering and leaving velocities. The heat absorbed was obtained from the weight of feed water and its temperature rise.

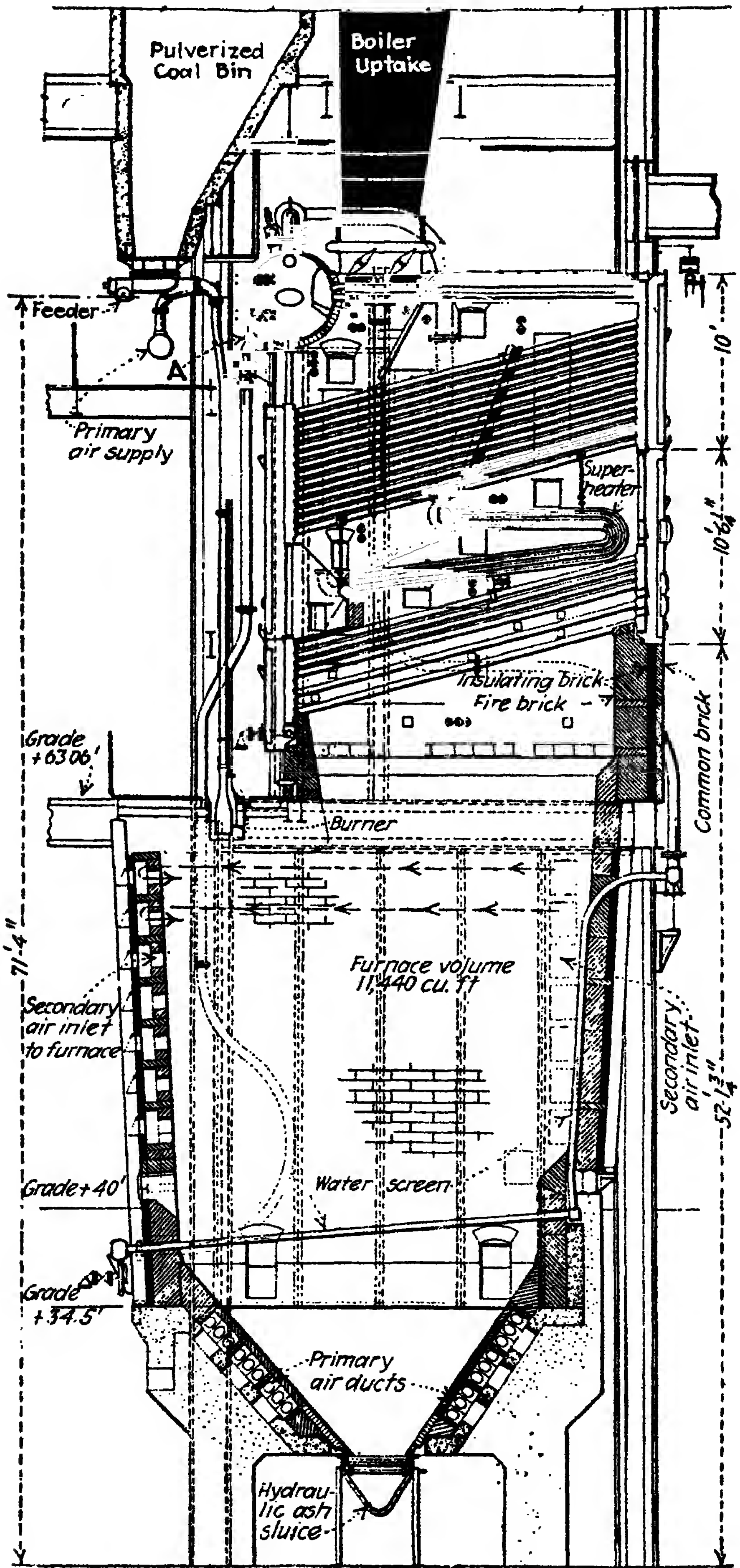

FIG. 90.—Features of the boiler and furnace construction in the Cahokia station of the Union Electric Light and Power Company.

The boilers are of the cross-drum B. & W. type and have 18,010 sq. ft. of heating surface. While four boilers serve each turbine, three of them will carry the load at 230 per cent

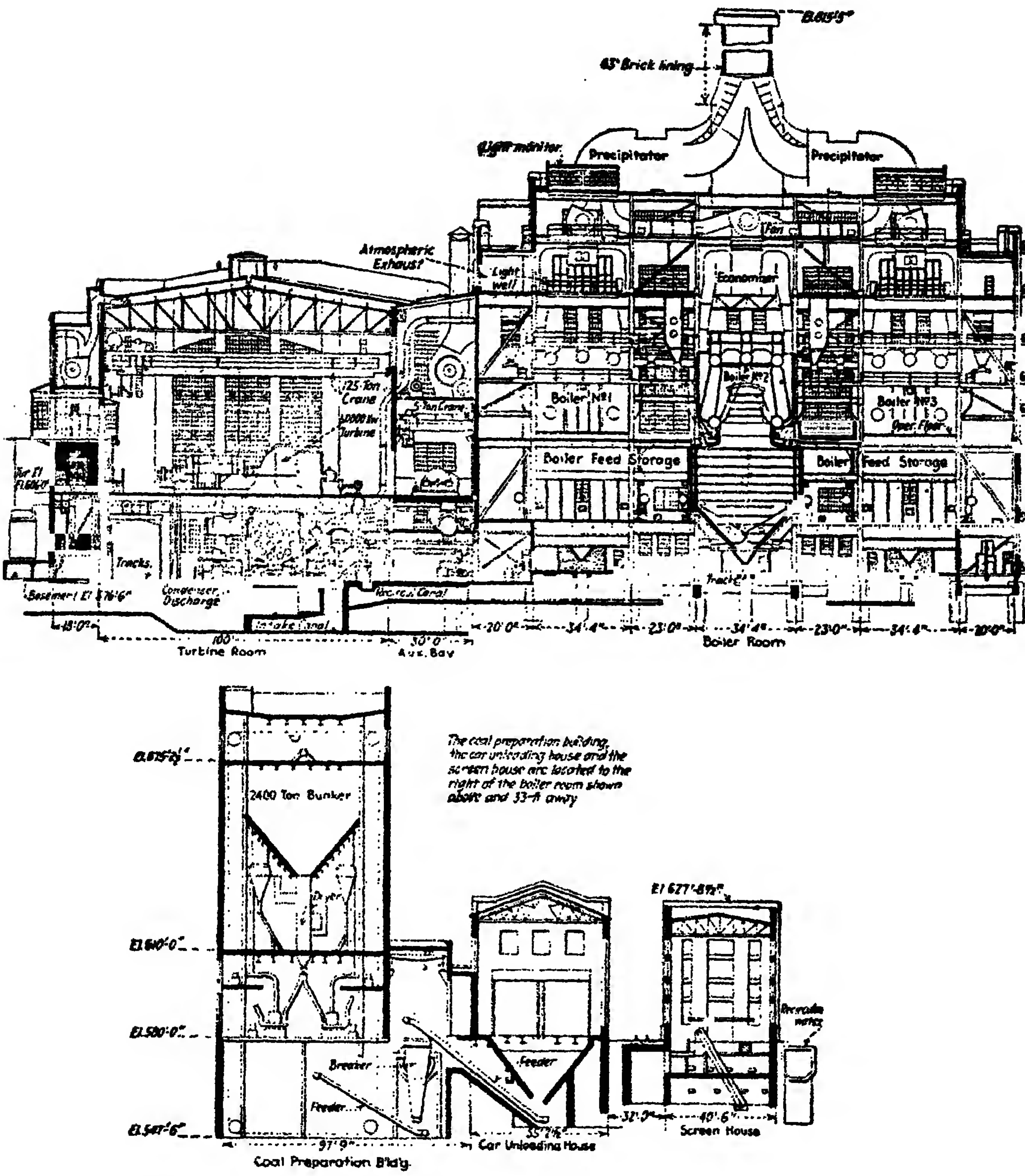

FIG. 91.—Cross-section of the Trenton Channel station of the Detroit Edison Company. Below; the pulverized coal preparation building, the car-unloading house and the screen house are to the right of the boiler house shown above and about 35 ft. distant.

---

rating. They are thirty-eight tubes wide by twenty tubes high, the tubes being arranged in two decks with an interdeck superheater above the lower six rows, which are exposed their full length to radiant energy. The two lower rows of tubes are double-spaced and not staggered, to avoid increasing the velocity of impinging gases carrying molten ash which might adhere to them. This arrangement cools the ash below the slagging temperature before it strikes the remaining tubes. No economizers are used because the coal costs only \$2.50 per ton. The feed water is heated largely by bleeding of main turbines. Steam conditions are 300 lb. pressure and 690°F. temperature at the throttle. Motor-operated valves are used at the header ends of the boiler leads and in the cross-over connection between headers. These permit closing the valves at some remote point in case escaping steam makes it hazardous for an operator to do it by hand, and also because the valves are so large and unwieldy that it would be an arduous task to operate them by hand.

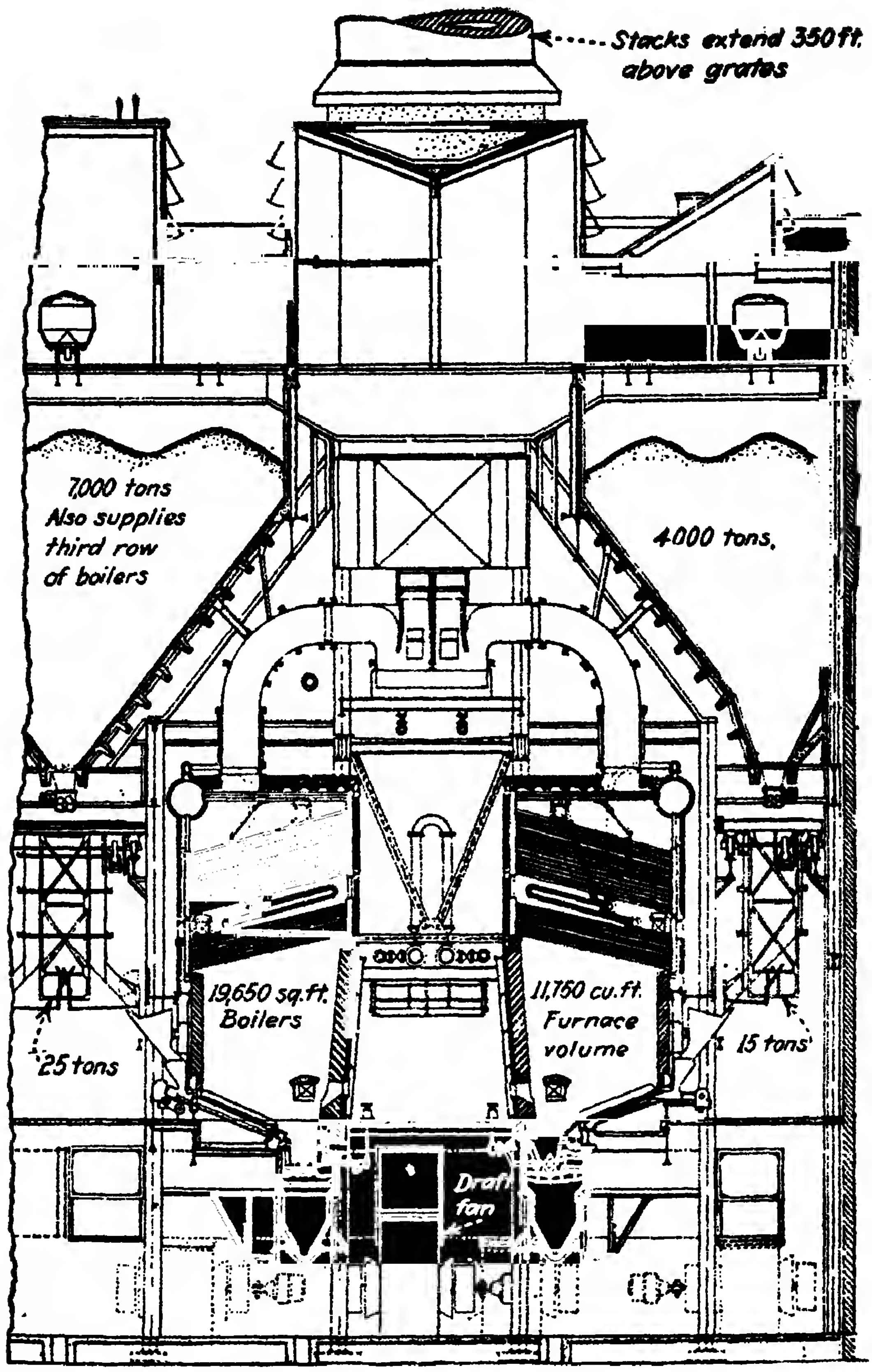

Fig. 92.—Cross-section of the boiler room of the Hudson Avenue station of the Brooklyn Edison Company.

Eight boilers are installed for the first group, each having 19,650 sq. ft. of heating surface, 2,508 sq. ft. of superheater surface and a combustion volume of about 7,500 cu. ft. The boilers are forty-two sections wide and twenty high in double-deck construction, with the superheater installed above the first deck of six tubes. They are fired with underfeed stokers and the settings have a weight of 21 ft. 10 in. from the floor line to the bottom of the uptake header. The inside width of masonry at stoker level is about 24 ft. 8 in.

The superheater is a single-loop type using 2-in. tubes and will give about 180° superheat at 100 per cent rating and 200° at 200 per cent rating with a pressure of 290 to 295 lb. in the drum.

The coefficient of heat transfer was computed from the formula:

$$U = \frac{2WR}{S(t_2 + t_1 - t_0 - t)},$$

U = coefficient of heat transfer.
S = square feet of heating surface.
W = weight of feed water, in pounds per hour.

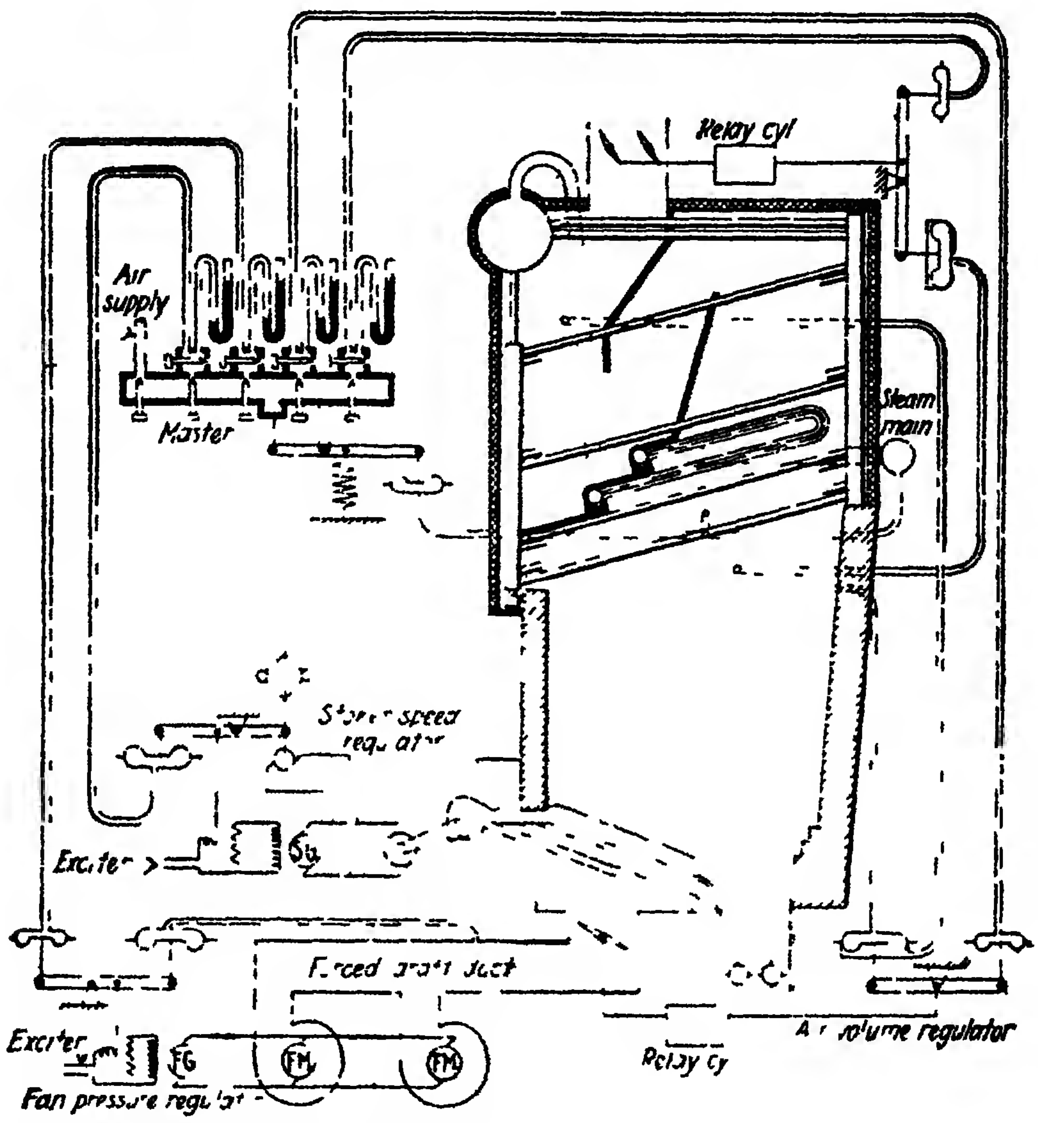

FIG. 93.—Diagram of a master controller and regulators for combustion control of one boiler in the Hudson Avenue station of the Brooklyn Edison Company.

The equipment consists of two types of controllers First, individual regulators for the dampers and the rheostats of the stoker and blower generators, second, a master controller to correlate the individual regulators There are two masters, one being a spare

The master controllers receive their activating impulse from the boiler steam pressure acting on a diaphragm, which is balanced against a coil spring A slight variation in the boiler pressure changes the position of the diaphragm and through a lever moves a small leak-off valve The chamber on which this valve is fitted is connected by pipes to each of the individual damper and rheostat regulators If steam pressure drops there is an increase in air pressure in the master controller and a proportional increase is transmitted to the individual regulators

R = rise in temperature of feed water, degrees Fahrenheit.
t = final temperature of feed water.
t_0 = initial temperature of feed water.
t_1 = final temperature of flue gas.
t_2 = initial temperature of flue gas.

Superheaters.—Superheaters are generally used in modern stations and the chief item in their selection and use is to secure

and maintain a constant superheat under variable boiler ratings. In general, the use of a large ratio of combustion volume to heating surface gives better control of superheat, but the location of the superheater in the boiler and the type of baffling used have a marked effect on superheater performance. The superheater should be equipped with safety valves and should be of the best construction and materials to withstand the severe operating conditions it encounters. Two-stage superheating and two superheaters in series have been used in boilers having small

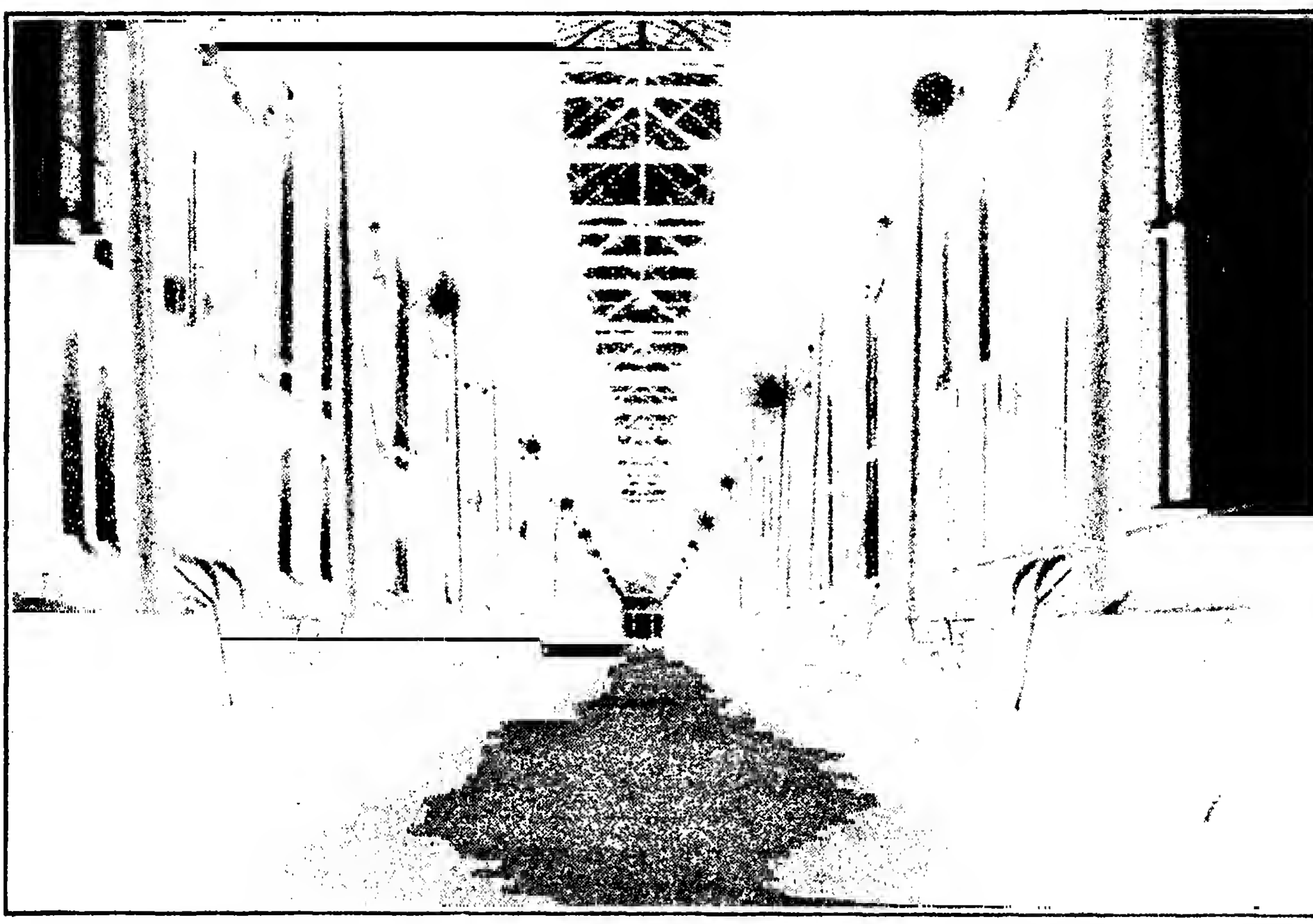

Fig. 94.—A firing aisle in the Quarry Street station of the Commonwealth Edison Company.

combustion chambers—one counterflow and one direct flow with respect to the hot gases. The radiant type of superheater is used in some installations and absorbs heat by direct radiation from the flames. With the use of high pressures and temperatures and high boiler ratings superheat control becomes increasingly difficult and increasingly important and the boiler, the fuel, the baffling and the feed-water regulation are important elements in obtaining satisfactory performance.

The pressure drop through the superheater varies with the rating and type of installation. For a Stirling boiler of 23,540-sq. ft. heating surface having a B. & W. Twin U-tube superheater, test data show a drop varying from 3.5 lb. per square inch at 100

per cent rating to 13 lb. per square inch at 220 per cent of rating. Test data on another installation are given in Table XVII.

TABLE XXVII.—SUPERHEAT TESTS ON A B. & W. BOILER[1]

	Test numbers			
	1	2	3	4
Duration, hours	1	1	4	4
Per cent rating	142	168	101	187
Draft:[a]				
(A minus)	0 32	0 39	0 15	0 43
(B plus)	0 01	0 06	0 06	0 05
Flue CO_2	14 0	13.55	14 1	13 3
Gas O_2	4 65	5.65	4 9	5 9
Analysis CO	0 95	0.5	0 43	0 5
Stack temperature	477.5	490	456 5	504 4
Boiler pressure	288	284	288 8	295
Degrees superheat	208.2	211 3	190 2	216 6
Room temperature	74	75	73	61
Feed water temperature	100	100	100	100

[1] Prime Movers Committee, N. E. L. A., 1923

[a] A = Draft top third pass

B = Draft in furnace

Cox stokers, buckwheat and anthracite

Stokers.—Mechanical stokers predominate in stations using coal, although many pulverized-fuel installations are used. The stoker has proved superior to hand firing and has been developed into three general classes:

1. Traveling-grate stokers carry the fuel fed from the front of the boiler slowly toward the bridge wall. They are adapted for burning low-grade fuels, such as coke breeze, anthracite fines and western coals. The fuel bed, as it passes different points, receives an appropriate volume of air at different pressures.

2. Underfeed stokers force the fuel upward toward the combustion area by means of screws or plungers. The fuel is commonly supplied along the center of the length of the grate and falls to the sides as it arrives at the surface of the fuel bed, forming a mound thick at the center and thin at the sides. Air inlets are supplied to give required amounts of air at the different locations. This type of stoker burns good grades of bituminous fuels very successfully.

3. Inclined overfeed stokers have sloping grates with the high portion near the front of the boiler where the coal is fed. Movable-grate bars feed the fuel along the grate surface and air is admitted between the grate bars or between them from a wind chamber located beneath the bars. These stokers burn a wide variety of fuels successfully.

The relative merits of the different types of stokers depend on the fuels used, the service demands and the design and type of

FIG. 95.—A firing aisle in the Northwest station of the Commonwealth Edison Company.

boiler and furnace. All give very satisfactory results in their proper fields of application. The rate of feed, the air supply and the maintenance requirements must receive constant attention to secure good operating results.

Fuel should be fed to the furnace no faster than it is consumed and stoker drives should have at least four-to-one speed ranges in order to maintain efficient operation. In a power station in which its turbo-generators supply alternating current it would seem that alternating current would be used generally for stoker drive, but alternating-current motors do not have their best applications where wide speed variation is required.

The methods of stoker driving are as follows:

1. Constant-speed motor with a mechanical connection to the stokers that will give a wide range of speed.

2. A wound-rotor induction motor having a speed range of two to one by secondary-resistance control combined with a selective-gear transmission, preferably of four speeds.

3. A four-speed squirrel-cage motor giving speeds corresponding to six, eight, twelve and sixteen poles, or speeds of approximately, 1,200, 900, 600 and 450 r.p.m. on sixty cycles, this

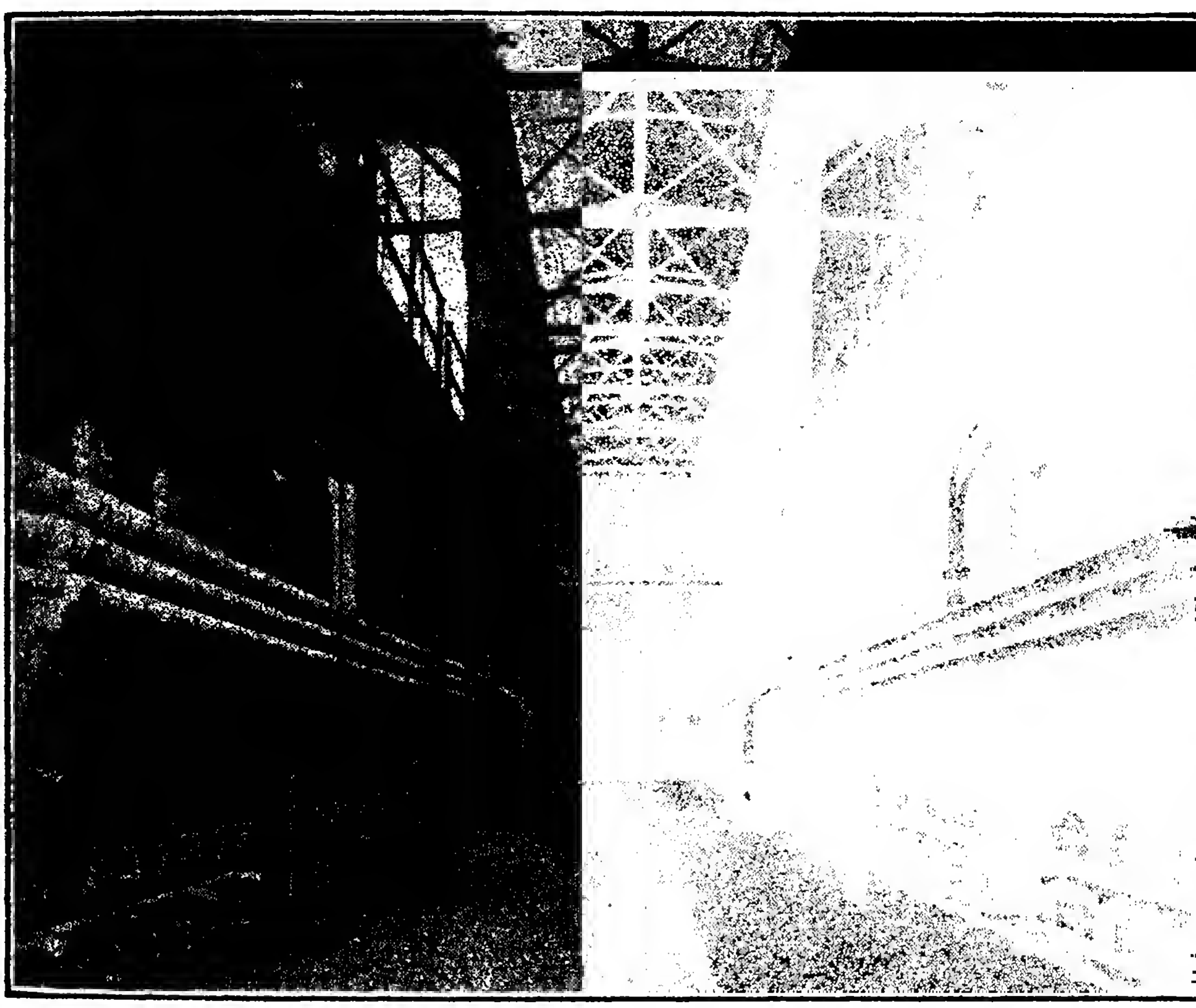

Fig. 96.—Boiler room in the Long Beach station of the Southern California Edison Company. Oil is used for fuel.

motor to have two- or four-speed selective-gear transmission. This device will give six to twelve fixed speeds if the gears are properly proportioned.

4. A commutator-type alternating-current motor giving a wide range of speeds by shifting the brushes.

5. A two-speed, wound-rotor motor giving a speed range of 1,200 to 600 r.p.m. by inserting resistance in the secondary and then pole changing to get 600 r.p.m. synchronous speed and reinserting resistance in the secondary to get from 600 to 300 r.p.m.

6. An adjustable speed direct current motor.

Refractories.—Most boiler refractories are made of fire clay as a base with additions of alumina, silica, iron or alkalies in small proportions. The limit to boiler combustion chamber temperatures is found in the refractories and the modern tendency toward large combustion chambers is due to the desire to achieve high boiler ratings with available refractories. Fire brick

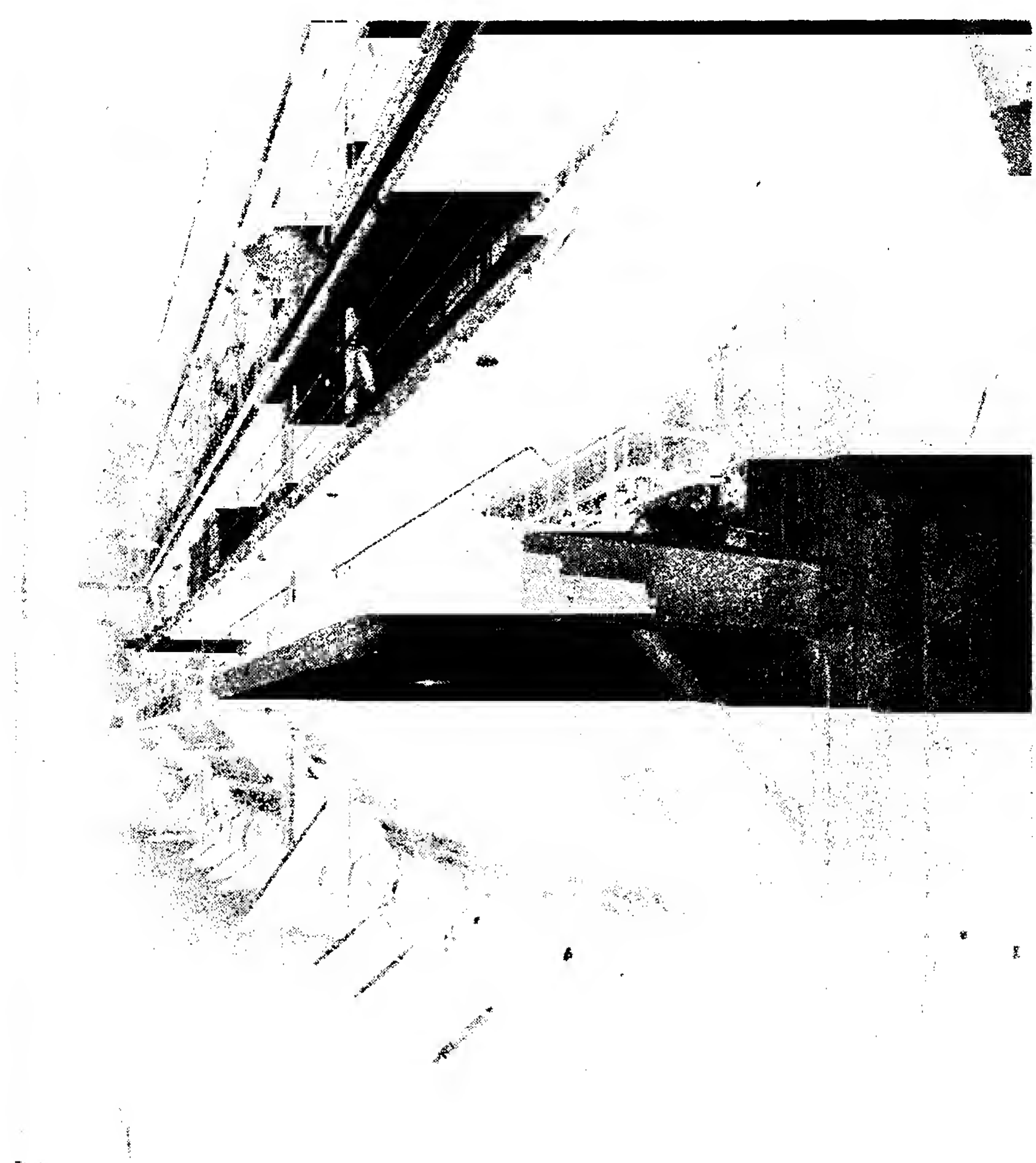

Fig. 97.—View of firing aisle in the boiler room of Hell Gate station of United Electric Light and Power Company in New York.

softens under load at about 2200 to 2900°F. and it is necessary to support it adequately if these temperatures are approached. Designs are made to accomplish this result but in addition steps are taken to cool the refractories by blowing air along the walls inside the furnace or by cooling the outside wall with air or water. The use of water cooling has led to the adoption of water screening on a large scale and installations have been made which use

bare or slightly insulated boiler-metal walls filled with water used in the boiler circulation. Along with preventing the softening and spalling of refractories, refractory cooling prevents clinkering and stops the fuel from adhering to the wall. Air admission through the furnace walls at proper locations is frequently used to accomplish this result on stoker installations.

Most boiler furnace refractories are made from a fire clay, the basis of which is kaolin, which when pure is composed of 46.2 per

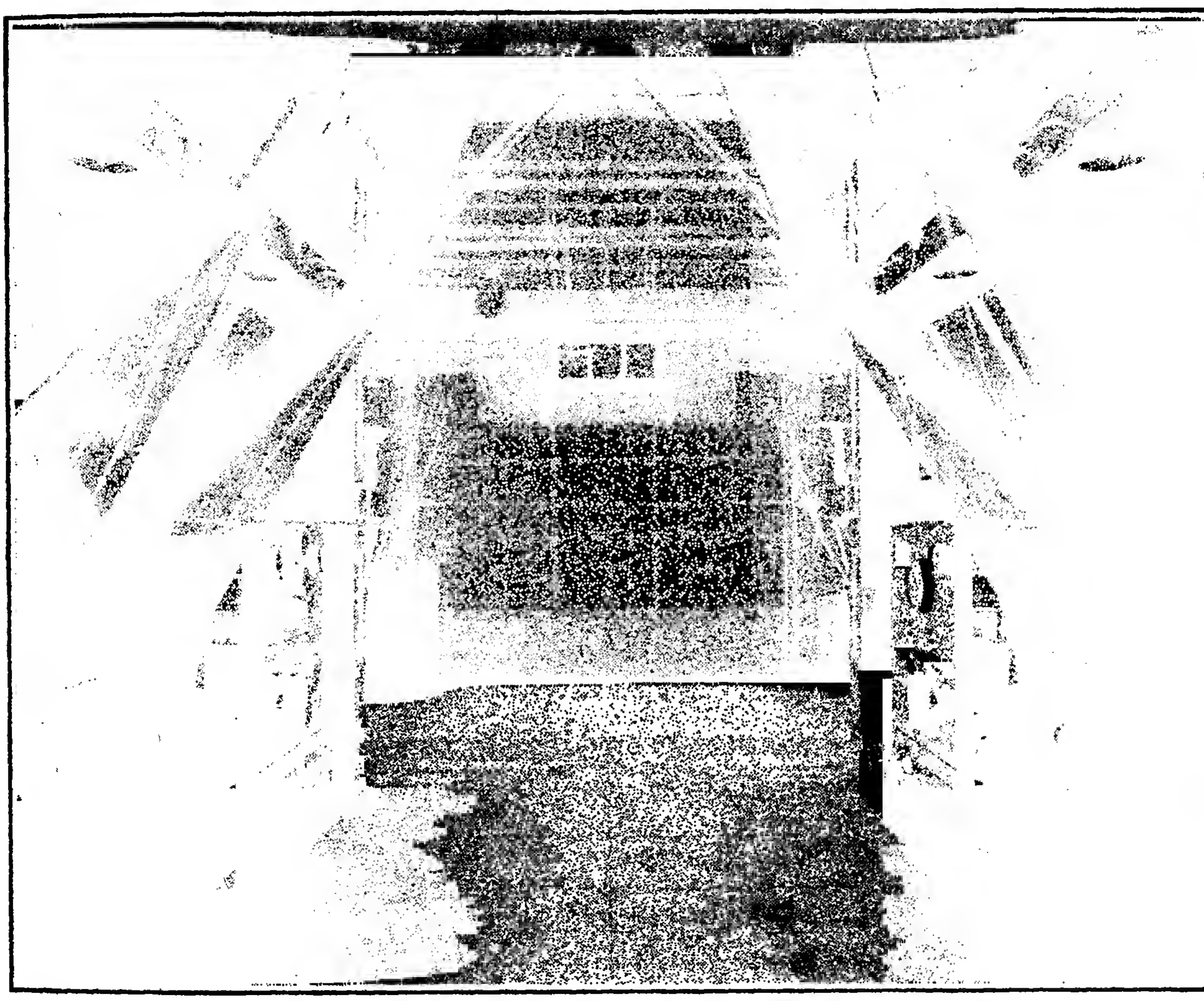

FIG. 98.—In this station control of all boiler operations is centered at the panel in front of each boiler.

cent alumina and 53.8 per cent silica, having a melting point of about 3200°F. As a general rule, the addition of alumina to kaolin, or fire clay, tends to increase its refractoriness, while silica, iron and the alkalies tend to lower it. Fire-clay bricks are usually made by blending a highly refractory flint clay with a bond clay which is usually lower in refractoriness than the flint clay, and if the blending is not properly and intimately done, the resulting brick may show the refractory properties of the weaker member rather than the average properties of both its constituents. For this reason, while the chemical analysis of a brick is

an indication of its refractory qualities, the analysis alone is not a safe guide, as quite a number of factors entering into the process of manufacture govern the ultimate structure and refractory properties of the product.

Light-burned fire brick will, when cold, withstand a pressure of from 400 to 750 lb. per square inch and hard-burned brick of from 2,000 to 3,000 lb. per square inch. Increasing the temper-

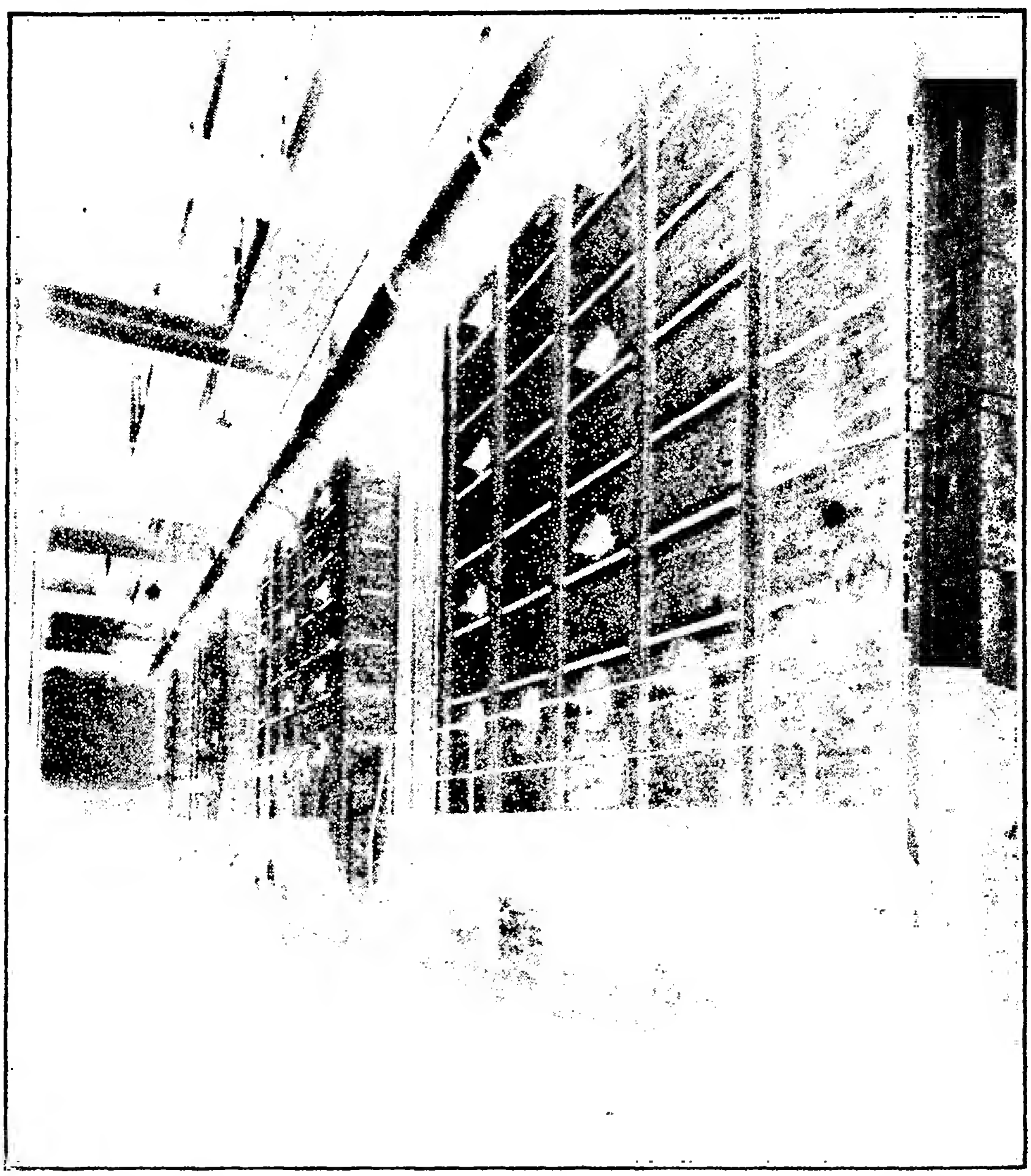

Fig. 99.—Rear of boilers in the Valmont station of the Public Service Company of Colorado. Pulverized fuel is used.

ature does not reduce the load-carrying ability of fire brick until a temperature of about 2000° is reached. Depending on the quality of the brick, it begins to soften under load at from 2200 to 2900°F. Most of the fire-clay bricks will commence to deform under 2500°F. More difficulty is not experienced in boiler furnaces from this source because high temperatures do not penetrate very deeply into the wall unless it is heavily insulated

and because of the general practice to use some form of wall ventilation or cooling.

The properties of some common types of refractories are shown in Table XXVIII.

TABLE XXVIII.—THERMAL PROPERTIES OF VARIOUS REFRACTORIES[1]

	Fusion point, degrees Fahrenheit	Point of failure under 50 lb. per square inch load	Thermal conductivity at 1832°F. B.t.u. per hour, per degree Fahrenheit per 1 in.	Specific heat at 212°F.
Fire clay........	3092	2462–2552	11.3	0.199
Silica...........	3092	2912	12.7	0.219
Magnesia.......	3929	2696	22.9	0.231
Chrome.........	3722	2597	16.5	
Bauxite.........	3245	2462 or more	11.3	
Zirconia........	4667	2750	Low	
Carborundum...	4064	Above 3002	67.0	0.186
Alundum.......	3722	Above 2822	High	0.198

[1] Prime Movers Committee, N.E.L.A., 1922.

The characteristics usually desired for a side-wall brick are large load-carrying capacity at high temperatures and low coefficient of expansion. For arch bricks, particularly where only one side of the brick is subjected to furnace temperatures, many users prefer a brick which has a slight initial softening at a temperature around 2300°F., but with a well-sustained strength for several hundred degrees higher. This characteristic of early initial softening relieves some of the compression strains in the arch and make it less susceptible to spalling.

Draft.—Forced-draft fans with capacities up to about 300,000 cu. ft. per minute are used in nearly all stations. Individual fans are used for each boiler in the unit system but in some installations the fans discharge into a common duct. These fans are motor driven by direct-current motors or variable-speed alternating-current motors with control of air-duct pressure either by hand or by remote control with automatic devices. Induced draft is a necessity for most plants operating at high ratings and using economizers or air heaters. In some cases economy or the necessity for eliminating the smoke nuisance may cause high

stacks to be built in preference to or in addition to the use of induced-draft fans. A by-pass should be provided on the induced-draft fans and economizers to permit of cleaning and repairs.

Stacks.—Lined steel, radial brick, reinforced concrete and a combination of tile and reinforced concrete are types of stacks used. Costs and questions of reliability and life determine which type is best to use and data are not yet conclusive. Reinforced-concrete and fire-brick-lined steel stacks are used very frequently, but their life and maintenance costs are yet to be determined.

FIG. 100.—Boiler room operating floor of the Big Sioux station of the Sioux City Gas and Electric Company. Pulverized fuel is used.

The proportioning of stacks is very important and but little can be had from empirical formula developed for small plants operating at low ratings. The fuel used, the draft system, the use of stokers, chain grates or pulverized fuel, the rating at which boilers operate, the furnace volume, the boiler and furnace design, the use of economizers or air heaters and the cost factors are all elements in determining the design and proportions of stacks.[1]

As a general start on the problem it is best to find the net area to allow the passage of the maximum volume of flue gases and then to determine the requisite height to give a draft in excess of all the draft losses plus the required furnace draft. At maxi-

[1] COTTON, ALFRED, "Chimney Sizes," a paper presented at Montreal before the A.S.M.E., May 28, 1923.

mum rating the total draft requirements in a large station may vary from 1.2 to 7 in. of water, depending on conditions. The use or non-use of economizers and induced-draft fans enter into the problem also. But having determined the maximum draft requirements and how it is to be obtained the stack height may be determined from these data and an estimate of flue-gas tem-

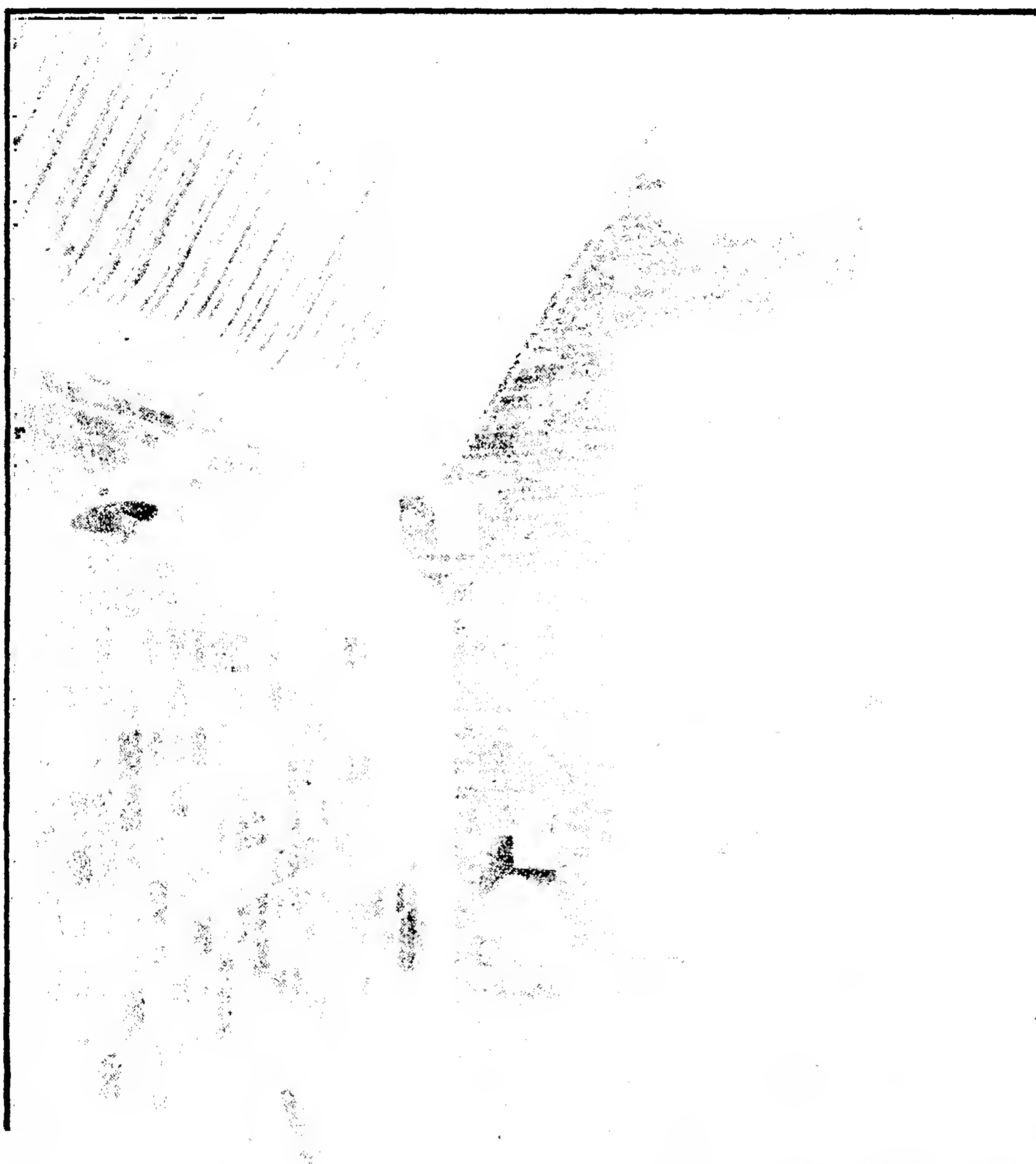

FIG. 101.—Interior of boiler combustion chamber in Richmond station of Philadelphia Electric Company. Note Bailey wall installation using metal steaming surface protected by special refractory blocks.

peratures. This temperature may vary from 200 to as high as 800°F., depending upon the equipment and the rating at which it is operated.

Flues are made of steel-plate construction with stiffeners at the angles. The layout of flues is made to follow the stream line of the gases to reduce draft losses and the areas are proportioned to keep the velocity of the gases about constant. Expan-

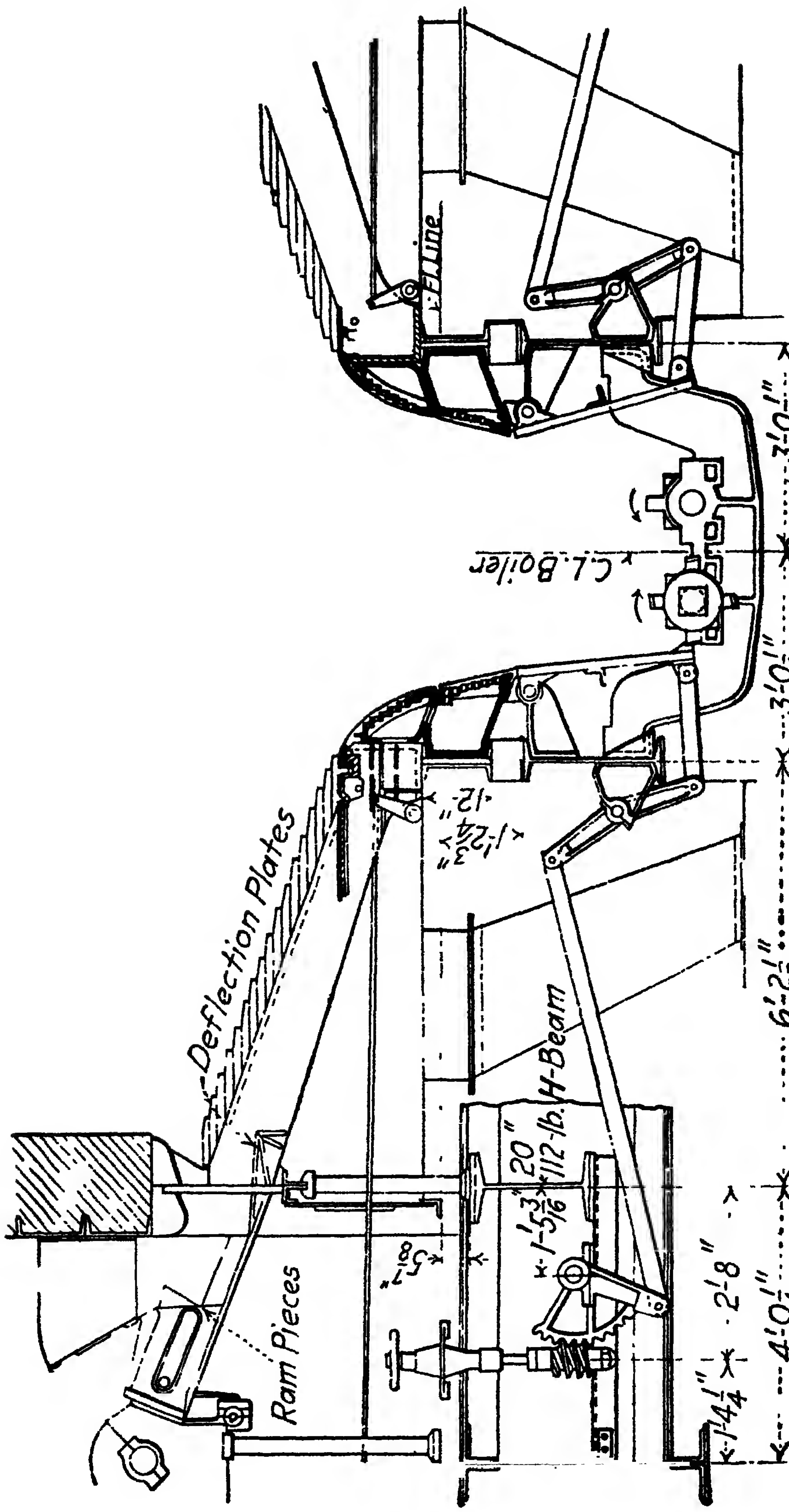

Fig. 102. Double-fired underfeed stoker setting used by Detroit Edison Company.

sion and contraction of flues and dampers must be provided for and it is desirable to insulate the flues to prevent excessive heat in the upper part of the boiler room. With the unit plan, one stack and one flue per group of two to four boilers is used, but a wide variation exists in practice. Cleaning-out doors and expansion joint connections to stacks should be part of the flue installations and the construction should be such as to insure a reliable air seal at all points.

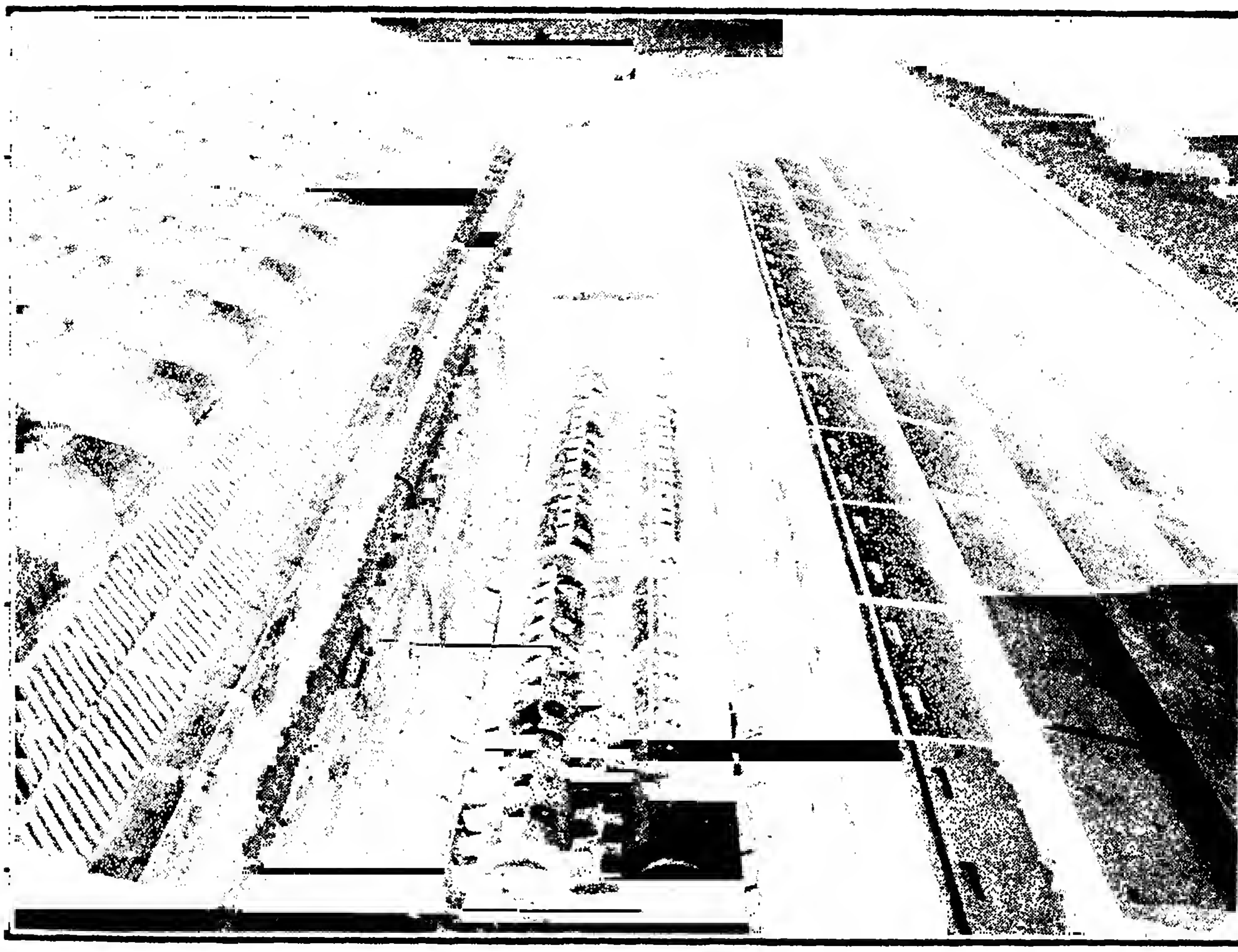

FIG. 103.—A deep pit with vertical walls feature this Westinghouse rotary ash discharge and underfeed stoker.

Station Piping.—Station piping should be well insulated and should be safe, flexible and simple. The location of valves, the types to use, the velocity to use and the size of pipe are elements to be determined by the designer. For insulation, many materials are available which give fair results. Among those commonly used are Nonpariel, Silocel and sponge felt, with the magnesia type predominating.

Expansion is usually cared for by using pipe bends and the data upon which the bends are based are very meager as is also the case with fixing the piping system by means of anchors. Roller anchors, spring anchors and fixed anchors are used, the fixed

anchors being used to prevent thrust on the turbine throttle. Steam velocities cover a wide range as indicated, as follows:

	Feet per Minute
Boiler leads	7,000– 9,000
Steam headers	6,000–12,000
Turbine leads	5,500–16,000

High-pressure joints are usually of the Vanstone or Sargol types with rolled or forged-steel flanges, and a great amount of research work is being done to secure better joints. All piping and valves should be identified by means of colored paint or some other method.

Figure 83 shows the piping for the Trenton Channel station of the Detroit Edison Company. Pipe sizes on the main steam lines in the Hell Gate station of the United Electric Light and Power Company vary from 10 to 18 in. outside diameters with steam velocities ranging from 6,800 to 14,200 feet per minute at normal loads. The main high-pressure piping is the controlling element in the station piping layout and it should be carefully designed on the basis of the velocities to be used.

The valves should be located conveniently to the operating force with a control station at the valve and at the central boiler-room control board.

Boiler Feed Water.—For boiler feed supply water need not be pure but must be suitable for steaming purposes. It must be free from air, carbonic acid, salts of ammoniac, decomposed foods, chlorides and must not produce scale.

Impurities in feed water produce one of the following effects in plant operation:

1. Internal corrosion.
2. Precipitation of solid matter (mud).
3. Formation of scale.
4. Scum, which causes foaming.

Any of the above effects makes for non-economic operation of the plant.

Corrosion is caused by the free acids and by air in the water. It may come from oil used, ashes, use of swamp or bog water, sulphuric acid from mine drainage water and from the air absorbed in the water. Alkaline water attacks copper fittings,

oxygen also attacks copper fittings; the alkaline water dissolves the oxide and lets the fittings again be oxidized.

Mud if deposited in the mud drum only requires blowing out, although it may also cement the scale in the boiler. Blowing out of boilers represents a great heat loss and should be done only when needed.

Scale effect depends on its density; the carbonates are soft and porous and are usually non-injurious; the sulphates are hard and

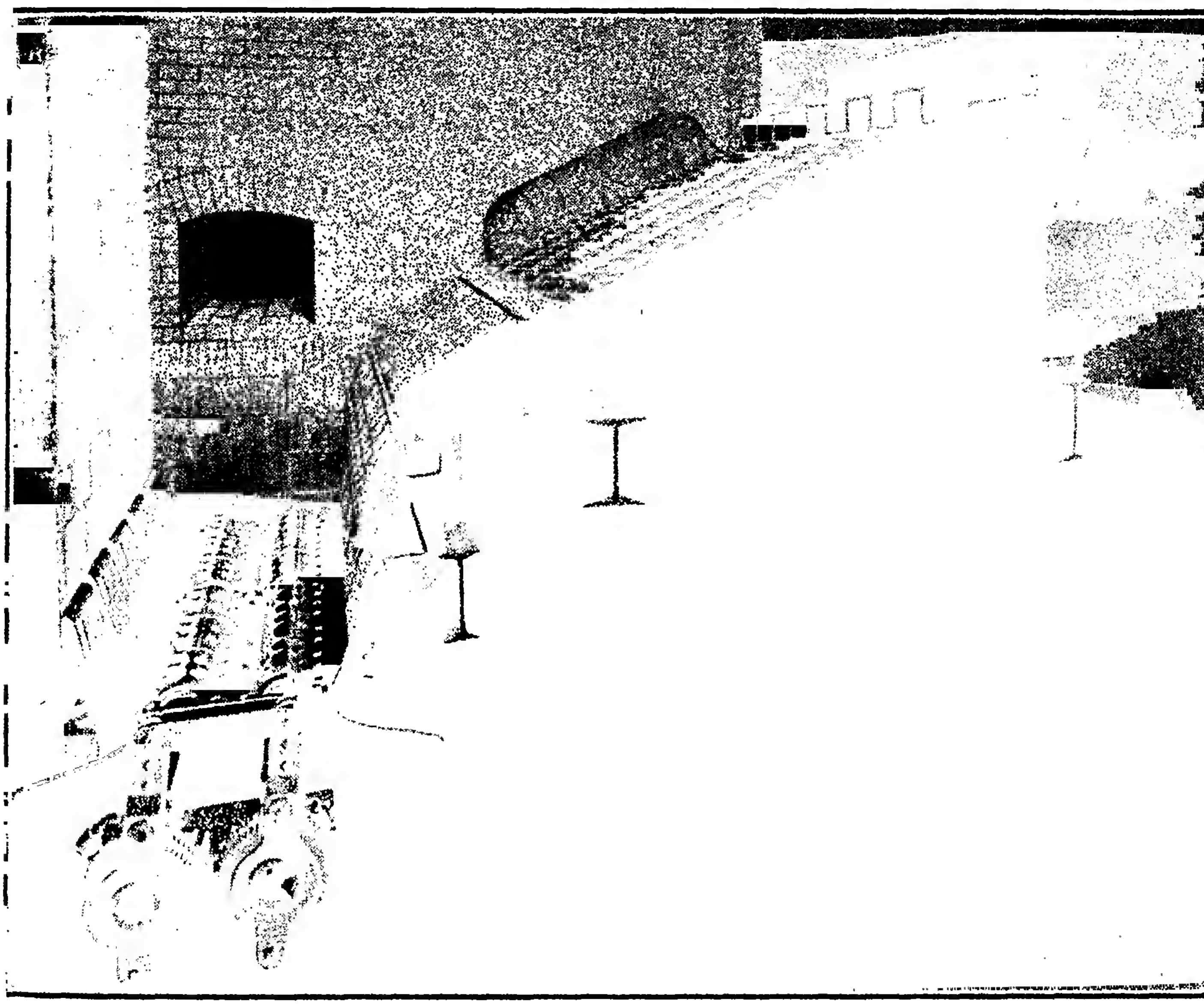

FIG. 104.—Rotary ash discharge with Taylor underfeed stoker.

impervious to water and are dangerous. The following are common scale-forming materials: $CaCO_3$, $CaSO_4$, $MgCO_3$ and $MgSO_4$.

The carbonates are only slightly soluble in water and are usually combined with CO_2, forming a soluble solution of bicarbonates in cold water but insoluble at temperatures above 200°F. due to the CO_2 being driven off. Manganese and calcium sulphates are the most troublesome and are not deposited until a temperature of 300°F. is reached.

Scum causes foaming. When soda is used in the feed water it may combine with the oil and saponify the feed water. Surface blow off is the best remedy.

In determining the feed-water system it is necessary to consider the kind of water that is available and what purification is best, the type of heaters and heating system to use, the auxiliary drives, the size of piping and head pumped against, the power used by steam and electric auxiliaries, the fuel cost and the installation charges. An economic equation can then be set up involving the variables, and the installation giving the lowest annual overall cost can be determined.

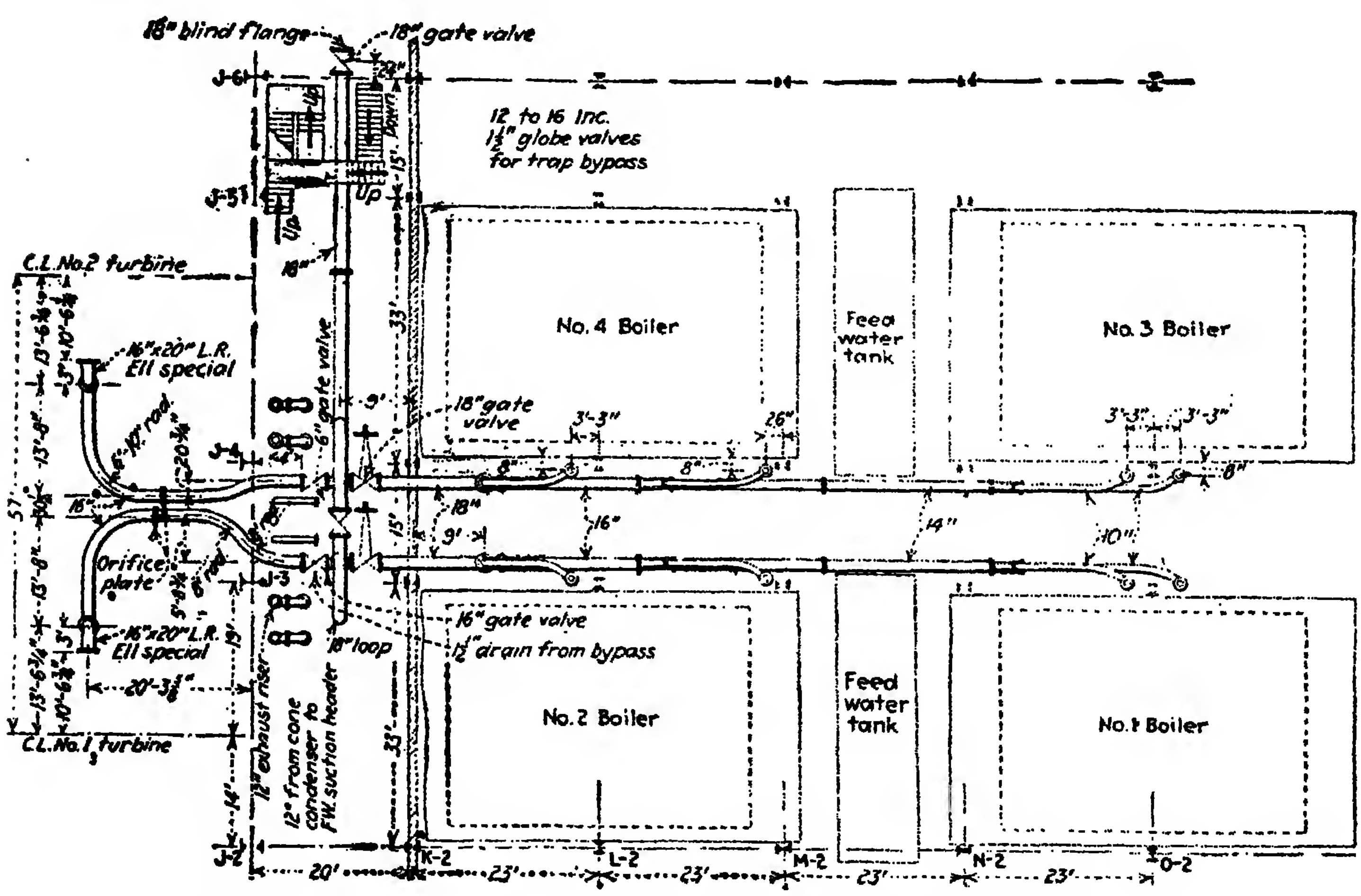

FIG. 105.—Main steam piping in Avon station. The location is below the operating floor of the boiler room.

The majority of stations use chemical treatment of some kind for conditioning the feed water. Deaërator systems have proved necessary and economical in large stations for eliminating the oxygen in the feed water. This treatment eliminates corrosion of iron and steel in boilers, economizers and piping and prolongs the life of the metals.

Of the feed-water systems used with varying degrees of success depending upon local conditions the most commonly encountered can be listed as American water softener, International cold or hot process, Permutit, Sorge Cochrane hot process, lime and soda hot process, Bartlett Graver, Borromite process, Dearborn, Gris-

com Russel evaporators, Vator, Scaife, continuous lime and soda, Reilly evaporators, lime, soda-ash copperas process, and Lillie evaporators. These differ in many details and the present tendency in the large systems is toward the use of evaporators. This results in changes in practice which have reduced the amount of make-up water to a very small value.

Accessory Devices and Metering Equipment.—Soot blowers, pumps, feed-water regulators, draft-control equipment and many other devices are used in the boiler room. The selection

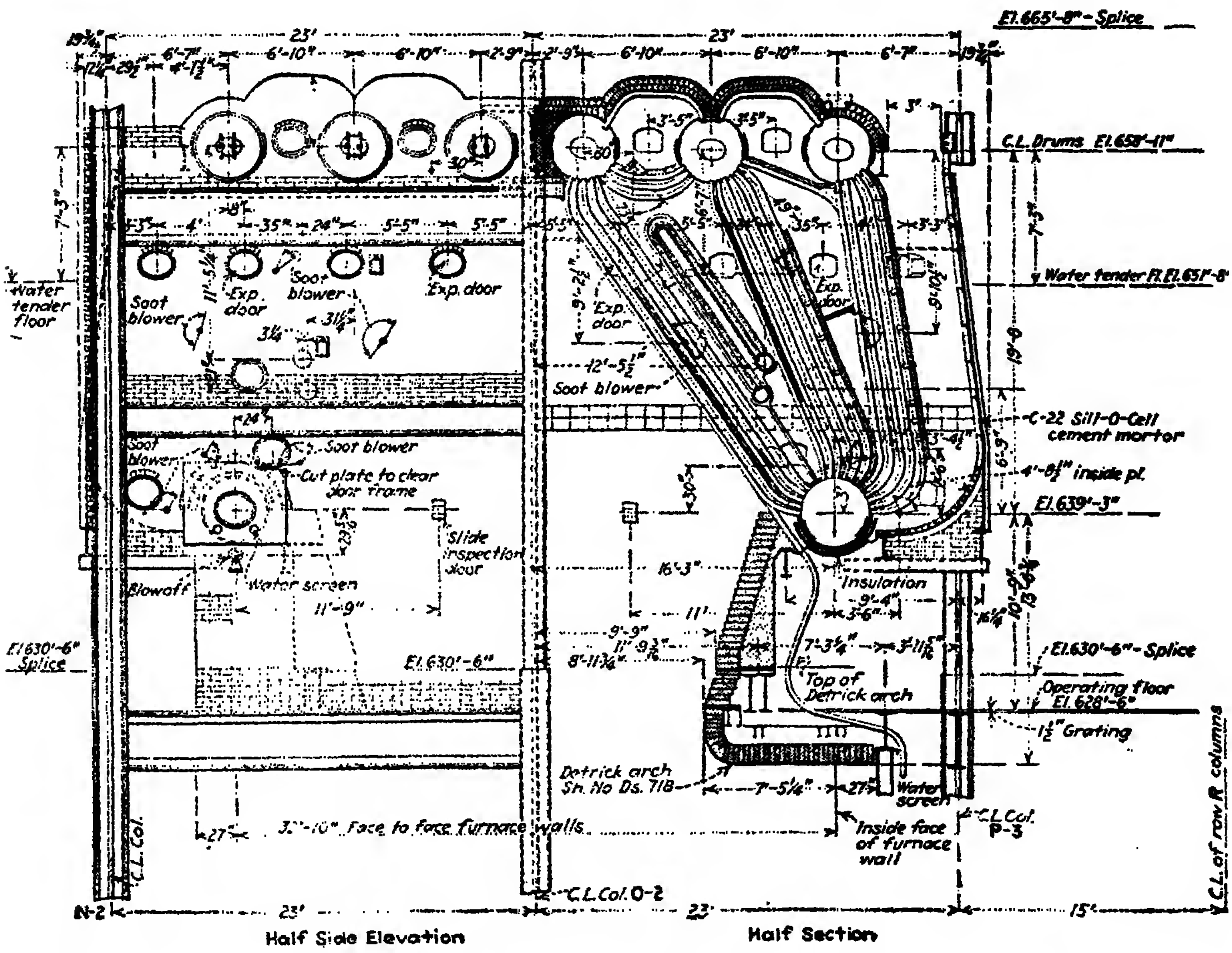

FIG. 106.—Side elevation and section of the boiler setting in Avon station of the Cleveland Electric Illuminating Company. Ultimate rating 300,000 kw.

and application of this type of equipment involve the utilization of the latest developments in the art as recorded in current engineering data. Very great improvements are being made constantly in control equipment and the tendency is to secure equipment which will eliminate the human element in station operation to a maximum degree so that highly skilled combustion engineers may operate and control the whole station from one central dispatching board located in the boiler room.

Metering Equipment.—The use of adequate and reliable meters in the boiler plant is essential to economical operation

and to afford a record of station performance. Indicating meters show what is going on continuously to the station operators; integrating meters record values over stated time intervals for economic calculations and graphic meters give a continuous and permanent record of equipment performance whereby the causes of poor economy or of accidents may be accurately determined.

Meters are of many types and may be divided into two main groups: (1) for securing economical operation, (2) for securing records and checking performance. For a modern steam station using coal, these groups are typified by the following meters:

Meters for boiler-room operations.

Water gage on each boiler (indicating).

Steam gage on each boiler (indicating and recording).

CO_2 meters on each boiler (indicating and recording).

Draft gages on each boiler (indicating and recording).

Coal weights (recording or indicating).

Ash volume or weights (indicating).

Water-pressure gages on feed pumps (indicating).

Feed-water level gages on heaters (indicating).

Steam temperatures on each boiler (indicating and recording).

Feed-water temperatures (indicating and recording).

Flue-gas temperature (indicating and recording).

Steam-flow meters on each boiler (recording).

Feed-water meters (recording and integrating).

Make-up water meters (recording).

Condensate water temperature (recording).

Aneroid barometer.

Atmospheric temperatures.

Gages on lubricating-oil applications.

Portable thermometers, gage test sets, flue-gas analysis sets.

Other instruments suitable for the equipment used in the particular station.

The data obtained should be used as quickly as read to maintain operation at maximum operating efficiency through comparison with what might be called standardized data determined by careful tests for the station under consideration. In addition, these data are necessary to determine the monthly and yearly operating records and to establish facts in the event that questions arise in the future about present operating conditions.

Economical Solution of Layout.—The foregoing discussion shows the intimate relationships existing between the various

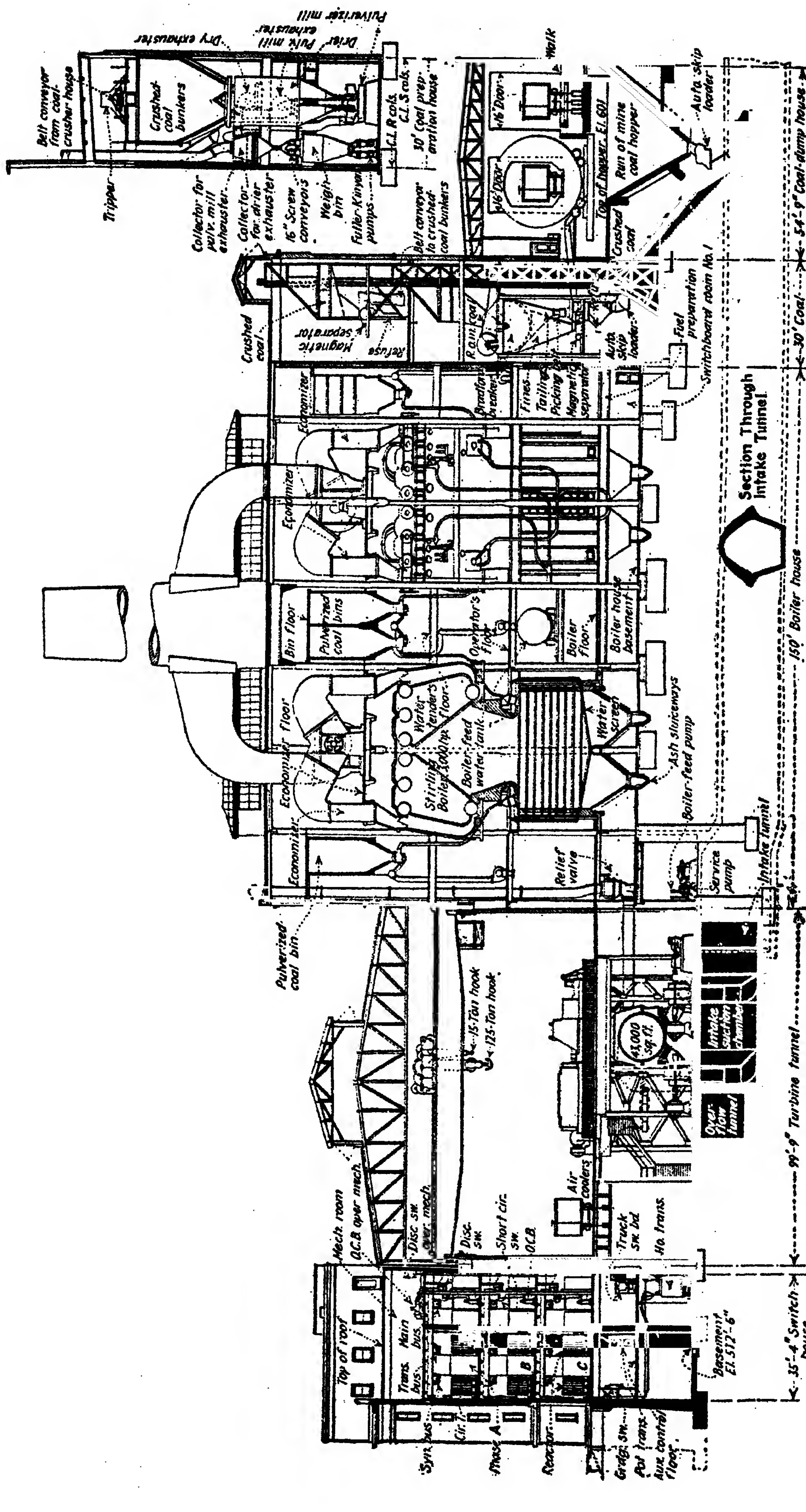

FIG. 107.—Cross-section of the 300,000-kw., Avon station of the Cleveland Electric Illuminating Company.

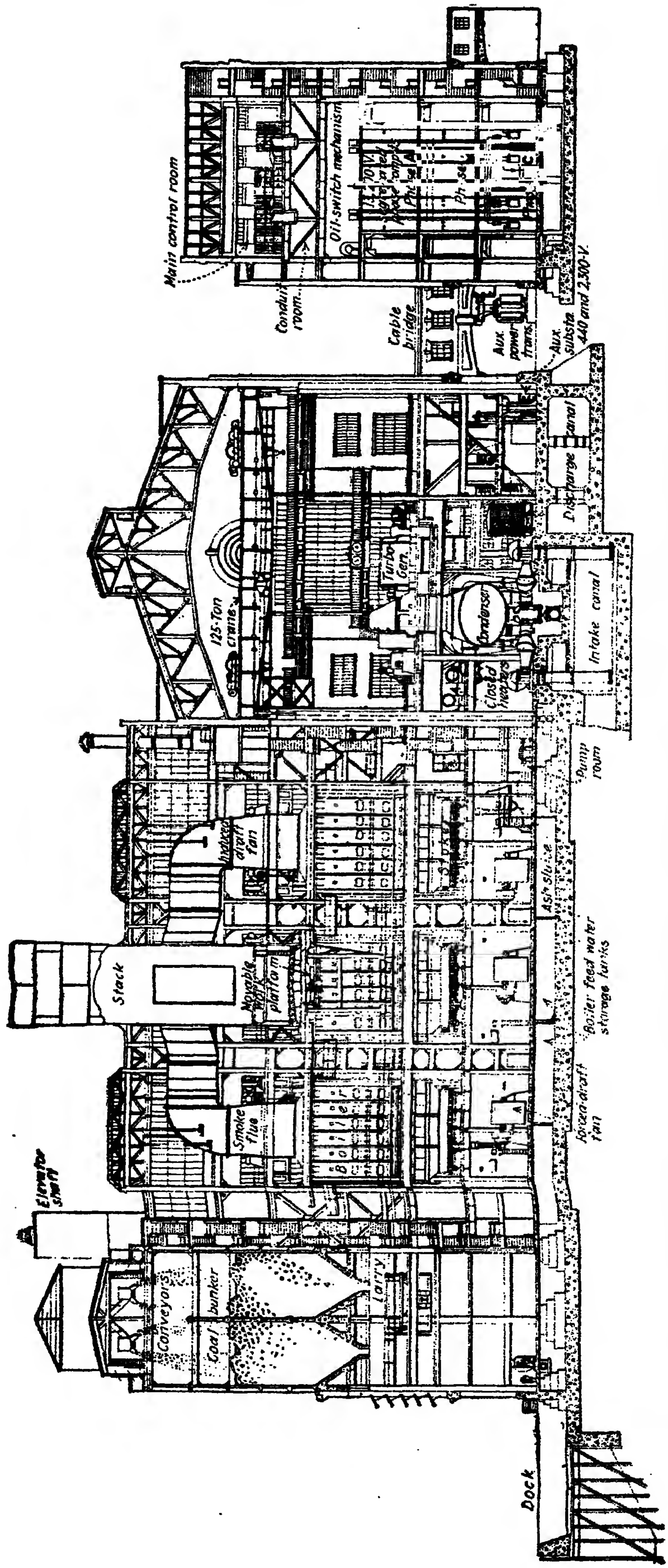

FIG. 108.—Cross-section of the 400,000-kw. Kearny station of the Public Service Electric Power Company.

items of equipment used in a modern boiler plant. The choice of one piece of equipment is linked very intimately with that of others and it is very difficult to connect the equipment in an economic equation that will consider all elements in the problem. In principle, each unit can be placed in an equation involving the pounds of coal used per kilowatt-hour, but the constants are very difficult to obtain because of the necessity for estimating heat transfers, efficiencies and operating performances. The result is that large stations are designed with some simple basic economic calculations. It is to be expected that thermo-dynamic data and combustion data will shortly be obtained so that fundamental equations can be used more largely in boiler-room design. The fundamental relationships are as follows:

Total steam = Plant rating in kilowatt × Steam consumption of main units in pounds per kilowatt-hour + Steam for auxiliaries + Losses. (1)

Total water from and at 212°F. = Factor of evaporation × Eq. (1). (2)

Water evaporated per pound of coal from and at 212°F. = B.t.u. per pound coal × Efficiency of boilers, ÷ 971.7. (3)

And the pounds of coal used per hour at full load $= \dfrac{\text{Eq. (2)}}{\text{Eq. (3)}}$. (4)

Therefore the kilowatt-hours per pound of coal = Plant rating in kilowatts ÷ Eq. (4). (5)

To apply the equation, it is necessary to know the efficiencies and energy consumption of all auxiliaries under operating conditions and the magnitude of the losses. Needless to say, this involves a great deal of estimation on the part of the station designer, but in the specific plant many of the fundamental data can be ascertained with a fair degree of accuracy and the preliminary design determined. As starting data it is necessary to know the load factor of the station, the size of the station, the cost of fuel and the manufacturers' guarantees on prime movers, boilers and auxiliaries under condition of steam pressure, steam temperature and vacuum assumed as the maximum that can be considered standard and safe practice.

CHAPTER VIII

TURBINES AND TURBINE AUXILIARIES

The selection of the steam equipment and auxiliary apparatus for the turbine room is intimately connected with the load factor of the station and its size. Modern steam turbines are very similar in principle, using the impulse action in the first stages and the reaction principle in the lower stages and there is no apparent limit to their ratings. Both the single-cylinder type and the tandem type are used in sizes up to 62,500 kva. and compound units have been designed and planned for use in ratings up to 200,000 kw. At full load the operating steam consumptions of the several types compare very favorably with each other so that the effect of variable-load conditions, mechanical-design differences, space occupied, costs and operating conveniences are governing factors in choosing the prime movers. Figure 115 shows the performance curves of two single-cylinder units from actual test data for various loads and conditions of vacuum. Figure 109 shows the thermal characteristics of one of the 40,000-kw. tandem units in Hell Gate station for specified operating conditions.

As a general practice, the system load is seldom an exact multiple of the rated capacity of the machines used, and in addition a spare unit is usually operated to care for fluctuations in demand and insure better reliability of the service. For these reasons even in base-load stations the average load on an installed unit will seldom be greater than 80 per cent of rating and the unit should be chosen to give minimum steam consumption at this load. For stations supplying loads having high peaks and with a low load factor, the point of highest economy may be as low as 65 per cent of the rated capacity of the prime movers. Thus the load conditions and the cost of fuel very definitely determine the amount of money to spend for securing units of high economy.

Foundations.—Since the turbine and the generator are mounted on one bed plate it is necessary to have a foundation sufficiently

large to afford support to the complete unit. Since the condenser is often mounted beneath the generator and turbine at about the center of the bed plate and at right angles to the longest bed-plate dimension, it is necessary to form a foundation with pier supports for the turbine. This gives the so-called "island" type of installation so frequently used consisting of a subbase and superstructure.

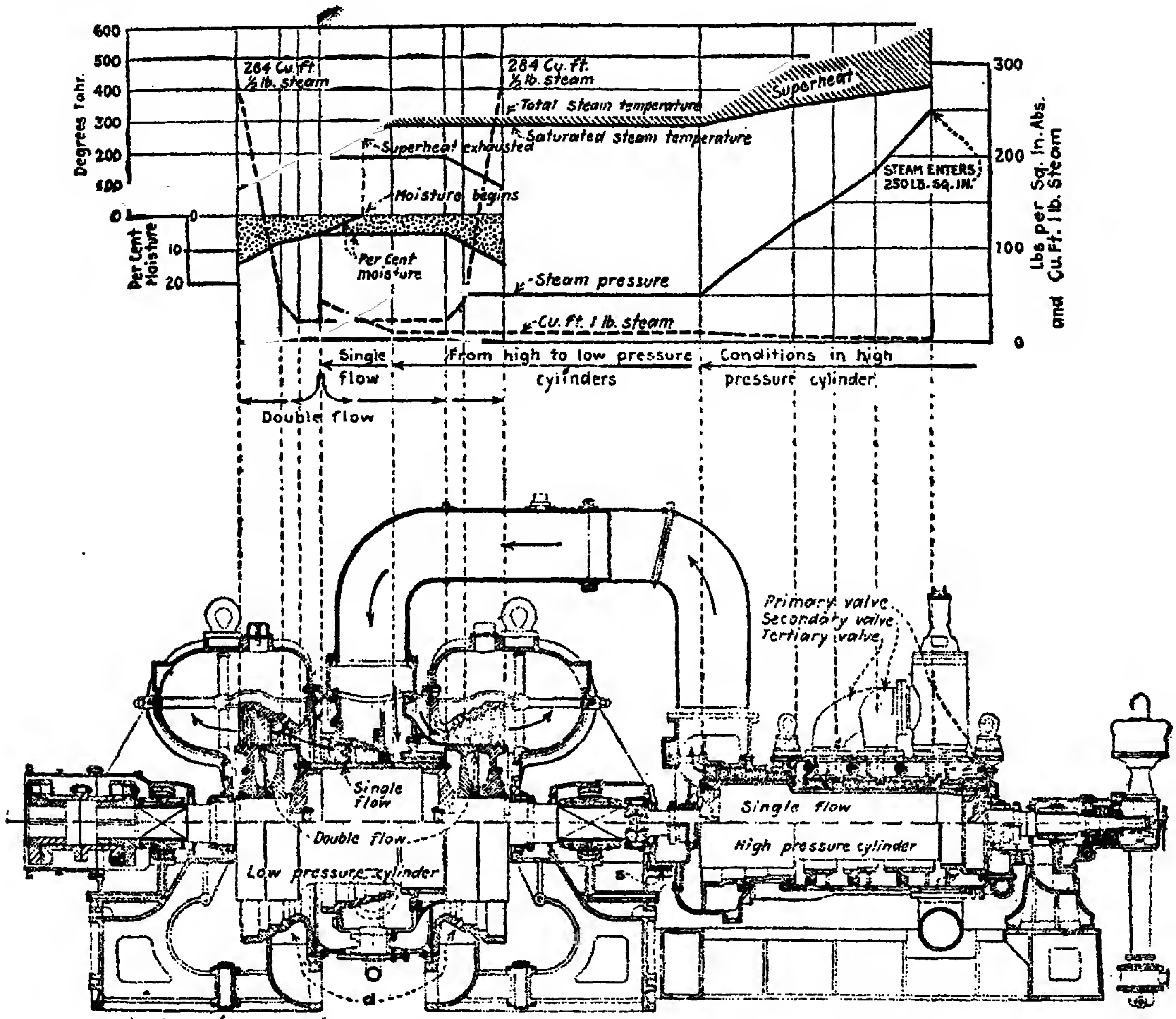

FIG. 109.—Steam conditions at 28,000 kw. on a 40,000-kw. Westinghouse turbine in Hell Gate station of the United Electric Light and Power Company, New York. Steam is admitted by the primary valve at 250-lb. pressure, the secondary valve is just beginning to open, and the tertiary is closed.

The subbase must furnish a solid support to the turbo-generator so that no movement can occur after the machine is installed. Although most soft soils will settle somewhat, this will do no damage if the settling is uniform under all parts of the foundation.

The concrete mixture for the subbase is about 1-2-5 and should be mixed and placed with extreme care and skill in conjunction with reinforcing. The use of reinforcing in concrete foundations should be eliminated where possible, as stray electric currents

produce rapid deterioration of the concrete in proximity to the reinforcing metal. The concrete mat is kept separate from building and should be at least 3 ft. thick. In computing the foundation dimensions, the total load on the soil will be the sum of the loads due to the weight of the foundation concrete, the dead turbo-generator weight and the pressure due to the bearing load or torque action in the generator. The moment due to the rotational or bearing load is very large and the sum of this moment and that due to the frame weight will be about twice the moment due to the frame weight alone. The outline dimensions and weights are given by the manufacturer and it is also customary for him to specify the details of the foundation so that the purchaser usually does not design the foundation. The exact solution of the foundation problem is obtained by using moments about the machine axes and involves fundamental principles in mechanics.

The superstructure is made either of reinforced concrete or of steel completely encased in concrete or with the spaces between steel members filled in with concrete. The height of the foundation above the subbase and its general design are largely governed by the space required for the condenser and its auxiliaries. With the smaller turbine units the condenser does not introduce much complication, but with the large size units it requires from 25- to 30-ft. height above the subbase and its installation becomes somewhat a problem.

Rigidity and mass are the chief requisites of the superstructure. The choice between steel and reinforced concrete or steel encased in concrete depends largely upon the space requirements for the condenser, and the individual ideas of the designer. Either type, properly designed, may be made to meet the needs of a particular case and the manufacturers of turbine units have not attempted to dictate which type shall be used. In practice, choice of types seems to be fairly evenly divided.

Vibration and the stresses liable to occur from impact due to unbalanced parts govern largely the calculation of the sizes of various members. It is common practice to double the calculated stresses to allow for impact and to reduce the allowable stresses in steel and concrete to from three-eighths to one-half those allowed for ordinary structures—in other words, the allowable stresses for steel would not exceed from 6,000 to 8,000 lb. per square inch.

As with the substructure, usual practice is to keep the foundation superstructure separate from the building structure. Very often the flooring immediately around a unit is supported directly on the foundation superstructure. This floor, however, is seldom more than 5 ft. wide and a joint is left where this floor meets the floor of the building.

The usual method of anchorage is by the use of anchor bolts built into the foundation piers or fastened to the steel. Ordi-

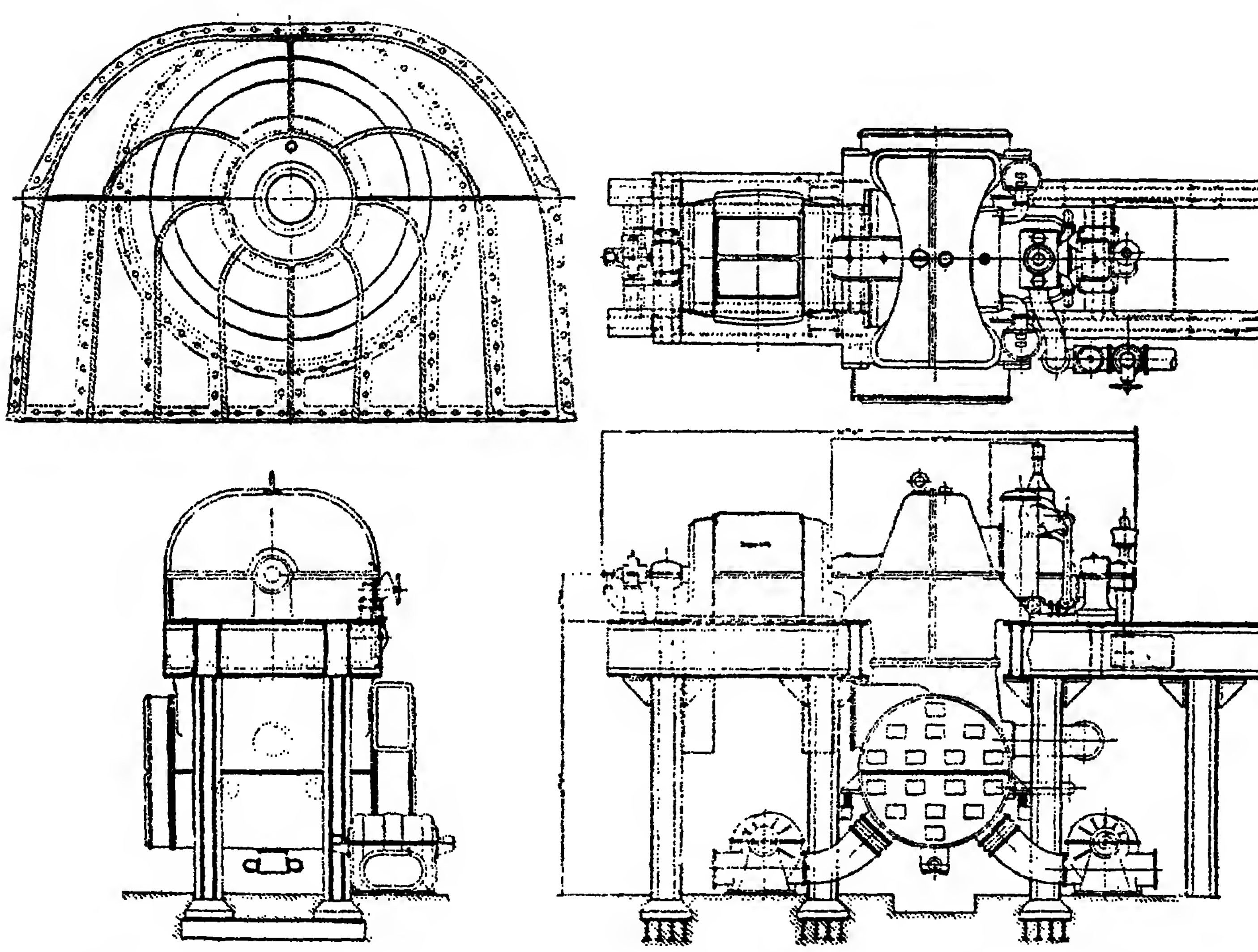

FIG. 110.—Assembly and foundation for a 30,000-kw. Westinghouse turbo-generator.

nary anchor bolts have a working strength of about 16,000 lb. per square inch, the shearing strength of concrete is about 40 lb. per square inch and the bonding strength about 80 lb. per square inch, so that the depth to insert the plain round-bar anchor bolt in concrete is $\frac{16,000}{80} = 200$ in. The diameter of the anchor bolt is determined by the load it will carry. As the above depth is very great, it is customary to use short rods with $\frac{1}{2}$-in. anchor plates on the lower end which are embedded into concrete where steel pillars are not available in the superstructure. These installations thus utilize the shearing strength of the concrete

more than the bonding strength. Figure 110 shows a modern turbine assembly.

Turbines.—Developments in turbine manufacture have been along lines designed to secure better mechanical and thermal performance in large and small units. Stream-line flow of steam through the units eliminates eddies and whirls and choking and increases the efficiency. Opportunity for steam extraction at one or several stages is also given in late designs. The greatest improvements have been made in securing better balancing of

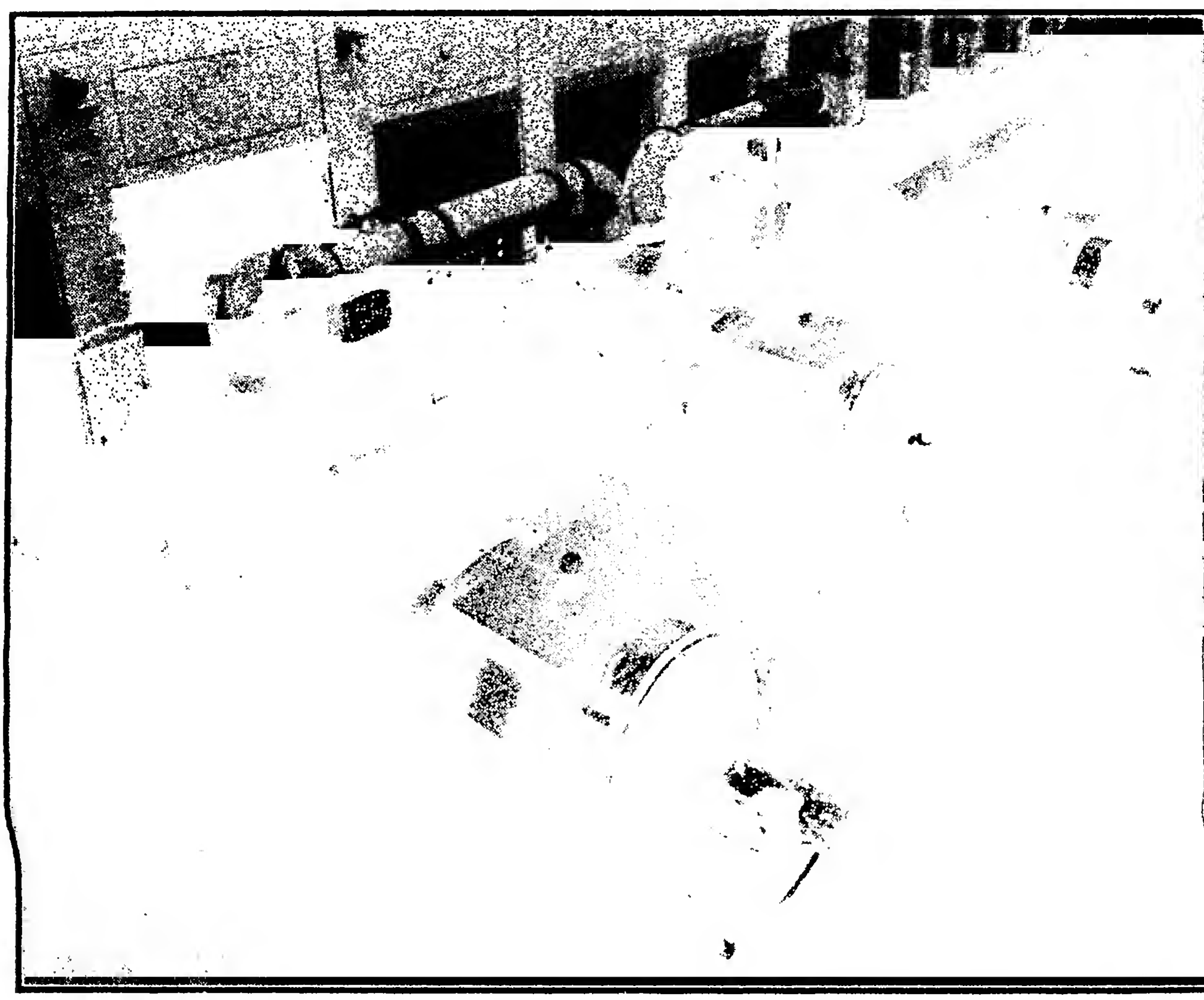

Fig. 111.—A triple-cylinder turbo-generator unit in the Colfax station of the Duquesne Light Company.

moving parts, greater reliability in materials and greater sensitivity and reliability in governors.

Turbine units can be obtained in sizes up to 200,000 kva. with ranges in pressure and temperature upwards of 600 lb. per square inch and 725°F., respectively. The triple-cylinder turbo units, while efficient and adapted to certain conditions of installation, are not used so much as the single cylinder and tandem designs in recent stations because of the greater use of the unit system in station operation.

In the 1923 *Report* of the Prime Movers Committee of the N.E. L.A., service records of seventy-four large turbine units were compiled and are given in Table XXIX. This table affords data for computing an average reserve capacity in turbine equipment to insure reliable service. In the more recent stations steam extraction from two or more stages of the turbine is used to heat

FIG. 112.—Two 25,000-kw. turbo-generator units in operation.

feed water. From 15 to 25 per cent of the steam which enters the throttle is bled before it enters the turbine condenser. This reduces the capacity of the turbine in terms of main unit rating and affects the rating of the generator slightly. Also the design of the turbine low-pressure stages should be modified slightly to care for the proportionate decrease in leaving losses, or the admission nozzles should be changed to admit more steam to the first stages.

TABLE XXIX.—SUMMARY OF OPERATING RECORD—1922

Seventy-four Turbine Units[1]

			Percentage of Period Hours
Installed turbine unit capacity		2,068,000 kw.	
Total period hours reviewed		642,902 hr.	100.0 per cent
Kilowatt-hours generated—total		8,885,504,000 kw.-hr.	
Service hours demanded		481,093 hr.	74.8 per cent
Service hours operated		437,902 hr.	68.1 per cent
Idle hours		205,000 hr.	31.9 per cent
Unit service demand factor		74.8 per cent	
Service demand availability factor		91.0 per cent	
Capacity factor		48.1 per cent	
Output factor		70.6 per cent	
Service hours factor		68.1 per cent	
Maximum possible service hours factor		84.5 per cent	
Steam Turbine			
Total hours of repair and maintenance		51,136 hr.	7.9 per cent
Steam casing and joints	1,141 hr.	2.23 per cent	
Governors	618	1.208 per cent	
Control gear	615	1.202 per cent	
Packings	1,800	3.520 per cent	
Nozzles	140	0.275 per cent	
Shaft and coupling	115	0.225 per cent	
Wheels or spindle	20,113	39.33 per cent	
Buckets or blading	2,485	4.86 per cent	
Vibration	5,565	10.88 per cent	
Bearings	1,824	3.57 per cent	
Lubrication system	901	1.76 per cent	
Cleaning oil system	1,663	3.26 per cent	
General inspection and overhaul	14,156	27.68 per cent	
Repairs during service demand	25,176	49.2 per cent	
Generator			
Total hours of repair and maintenance		20,506 hr.	3.1 per cent
Vibration	465 hr.	2.26 per cent	
Oil leakage	44	0.215 per cent	
Armature core	1,050	5.13 per cent	
Armature winding	9,771	47.6 per cent	
Field winding	5,838	28.4 per cent	
Collector rings	423	2.06 per cent	
Exciter	46	0.225 per cent	
Fans and ventilation	693	3.38 per cent	
Inspection and cleaning	2,176	10.5 per cent	
Repairs during service demand	10,430	50.7 per cent	

[1] N.E.L.A., 1923.

TABLE XXIX.—SUMMARY OF OPERATING RECORD—1922.—(*Continued*)

Condenser

			Percentage of Period Hours
Total hours of repair and maintenance	16,369 hr.		2.5 per cent
Leakage	2,071 hr.	12.65 per cent	
Cleaning	9,154	55.92 per cent	
Tubes	2,386	14.58 per cent	
Shell	13	0.08 per cent	
Circulating pumps	1,692	10.34 per cent	
Hot-well pumps	262	1.60 per cent	
Air pumps	454	2.77 per cent	
Miscellaneous	337	2.06 per cent	
Repairs during service demand	3,694	22.5 per cent	
Other Causes			
Total hours of repair and maintenance	11,448 hr.		1.8 per cent
General piping	1,201 hr.	10.5 per cent	
Plant electrical	1,720	15.0 per cent	
Outside electrical	70	0.6 per cent	
Miscellaneous	8,457	73.9 per cent	
Repairs during service demand	3,086	26.9 per cent	
Idle			
Reserve ready for immediate starting	105,248 hr.		16.6 per cent

In many recent installations, arrangements are made to permit the generator to be disconnected from the turbine quickly. With a closed system of ventilation on the generator this arrangement readily adapts itself to using the generator as a synchronous condenser when disconnected from the turbine.

Contract Details.—For large turbines a special contract, covering conditions at the time of purchase, is made with the manufacturer. A sample contract is given below, but the data are to be taken as typical and not as specific for the unit considered. In all probability greater efficiencies can be obtained in units of the present period and with the clauses changed.

SAMPLE CONTRACT FOR PURCHASE OF 50,000-KVA. TURBINE

The turbine manufacturing company proposes to furnish apparatus as herein described subject to the following conditions and specifications.

The manufacturer agrees that it will at its own expense defend all suits or proceedings instituted against the purchaser and pay any award of damages assessed against the purchaser in such suits or proceedings, in so far as the same are based on any claim that the said apparatus or any part

thereof constitutes an infringement of any patent of the United States, provided the purchaser gives to the company immediate notice in writing of the institution of the suit or proceeding and permits the company through its counsel to defend the same and gives the company all needed information, assistance and authority to enable the company so to do. In case such apparatus is in such suit held to constitute infringement and its use is enjoined the company, if unable within a reasonable time to secure for the purchaser the right to continue using said apparatus, by suspension of this injunction, by procuring for the purchaser a license or otherwise, will, at its own expense, either replace such apparatus with non-infringing apparatus, or modify it so that it becomes non-infringing, or remove the said enjoined apparatus and refund the sums paid therefor.

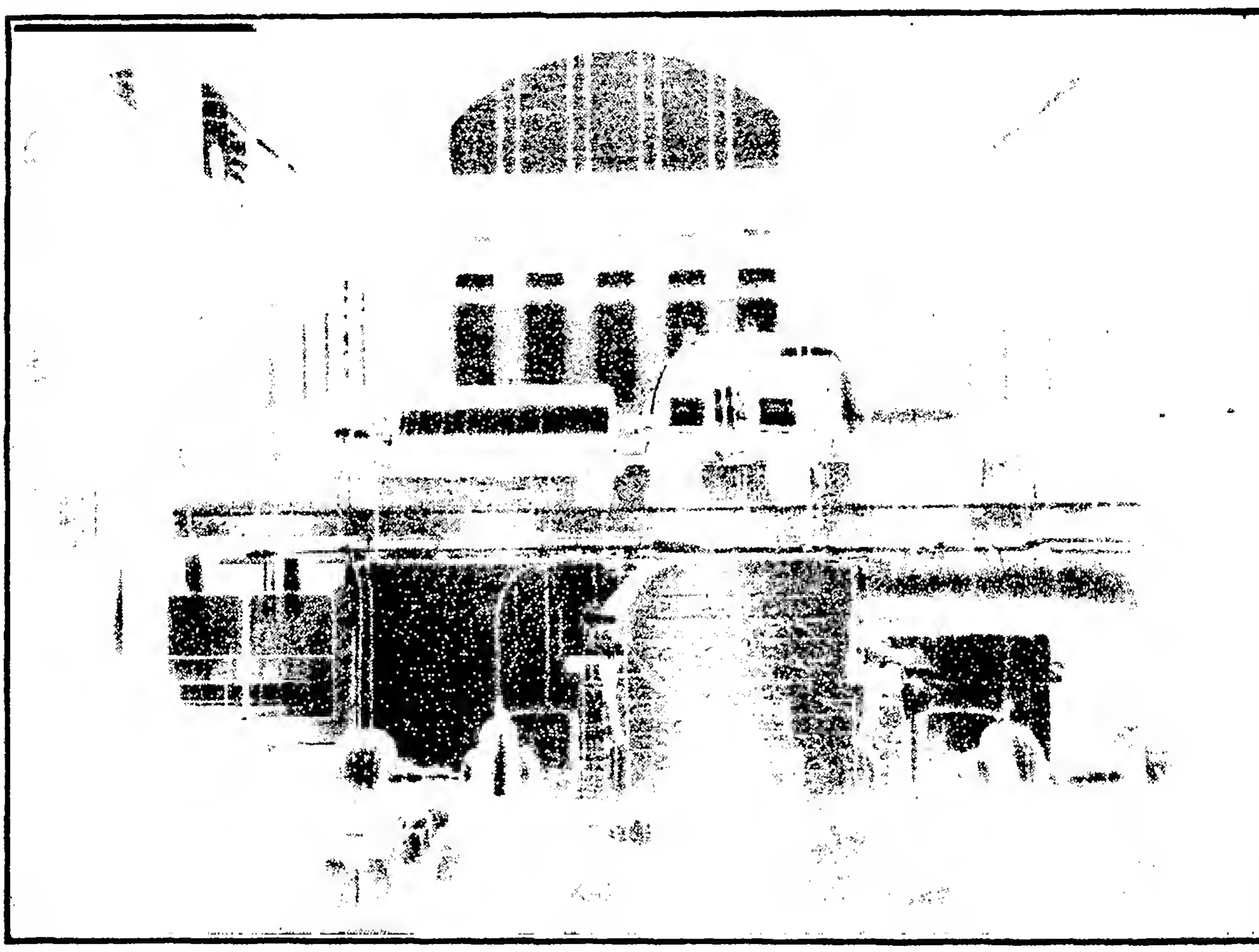

Fig. 113.—Interior of turbine room of Richmond station of the Philadelphia Electric Company showing a 50,000-kw., unit.

The company warrants the apparatus to be as specified herein and agrees to correct any defects in the apparatus which develop under normal and proper use within 1 year from the starting thereof, provided the purchaser gives the company immediate written notice of such defects. The company agrees that the installation, if made by it, shall be done in a thorough, workman-like manner. The company shall not be held responsible for work done, apparatus furnished, or repairs made by others.

The purchaser agrees to care properly for all apparatus and material delivered until the same is fully paid for, and to hold the company harmless against the payment of any taxes assessed against the apparatus and material after it shall have been shipped. If the installation is made by the company, the purchaser agrees without charge to furnish for the company

all necessary storage, rights of way, permits and authority for the installation and operation of the apparatus hereunder, and to reimburse the company for any loss incurred by reason of delays in starting the apparatus and completing the works that are not chargeable to the company; to designate the location of the apparatus herein specified before the work is begun, to pay extra for any changes made in location after same has been placed, and for any work performed or apparatus or material furnished in addition to that herein specified, and, furthermore, that the apparatus, after the starting thereof, shall be operated by the purchaser. The apparatus shall be con-

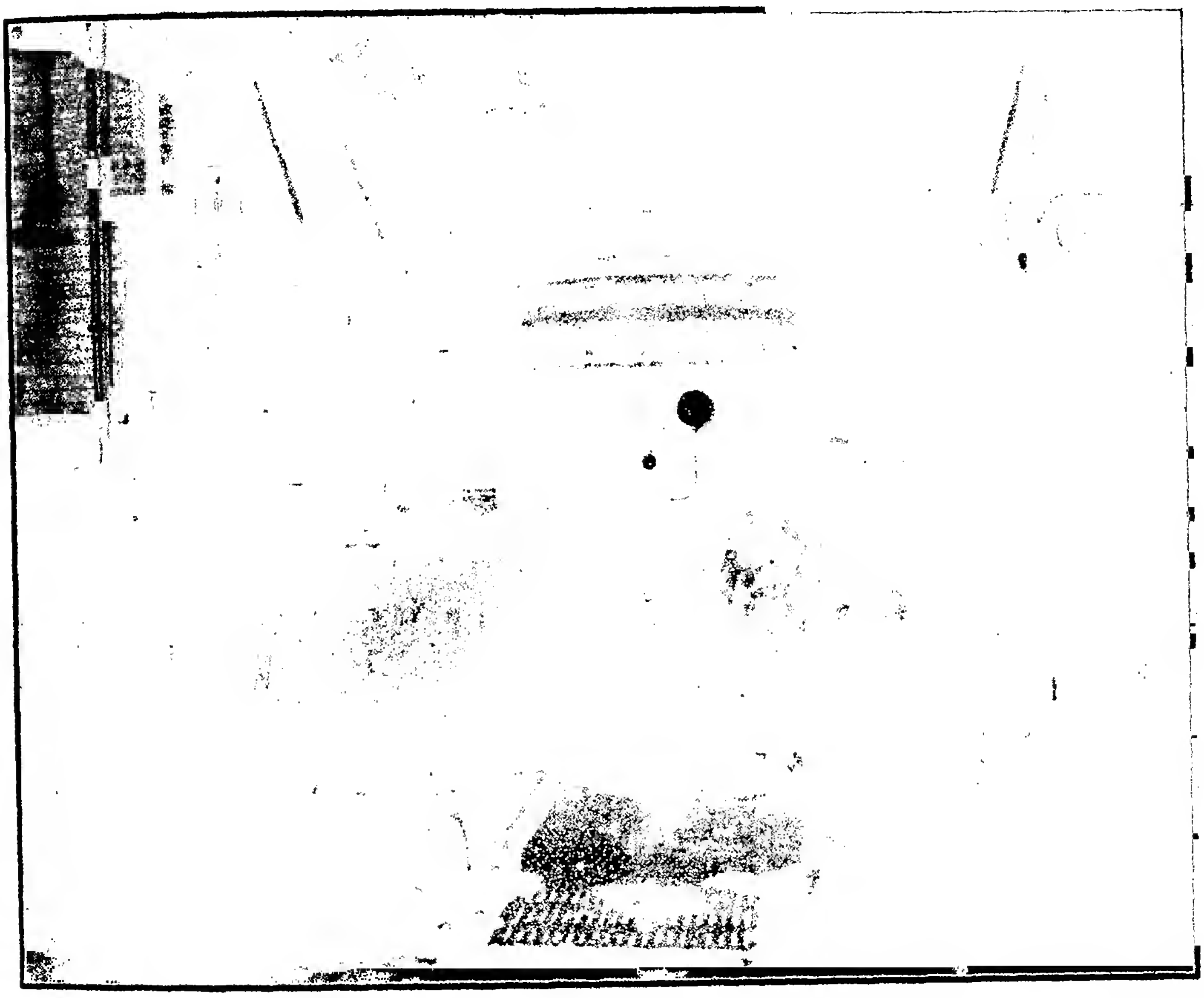

FIG. 114.—Typical arrangement of circulating water connection to a condenser in the South Meadow station of the Hartford Electric Light Company.

sidered as starting when first put in operation. The company shall not in any event be held responsible or liable for any loss, damage, detention or delay caused by fire, strikes, civil or military authority, or by insurrection or riot, or by any other cause beyond its control, nor in any event for consequential damages. Receipt of the apparatus by the purchaser shall constitute a waiver of any claim for loss or damage due to delay. Apparatus shall be installed by and at expense of purchaser unless otherwise expressly stipulated.

To enable the company to proceed with the construction of the apparatus, the purchaser agrees to furnish promptly on demand by the company all the necessary information as to details to be determined by the purchaser and that there will be no delay by the purchaser in the doing of any act required

for the performance of this agreement. In case of delay caused by the purchaser, shipment shall be extended for a reasonable time based on period of purchaser's delay and conditions at the factories which supply the company.

It is agreed that the apparatus herein specified shall be delivered by the company at place of manufacture, and that it is at the risk of the purchaser after its delivery on board cars at point of shipment, unless other delivery is expressly stipulated.

It is agreed that the company shall insure said apparatus sold hereunder against damage or loss by fire for its full selling price, as stated, for the

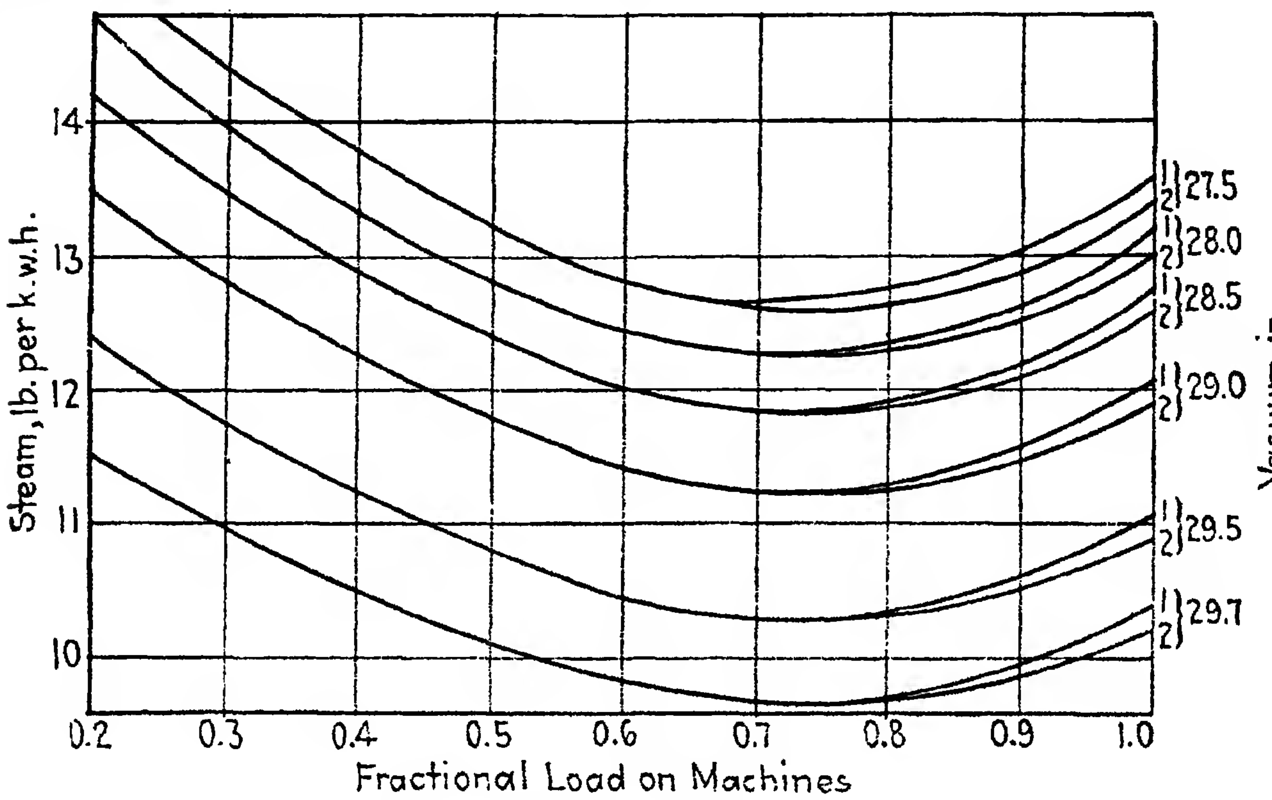

FIG. 115.—Performance of large turbine under variable test conditions.

benefit of itself and the purchaser, as their interests may appear until, but not after, under the contract the title to the apparatus shall have passed to the purchaser hereunder; and the purchaser agrees to pay the company for premium for such insurance one-fourth of 1 per cent on the total amount insured for each 3 months or fraction thereof after the delivery of said apparatus on board cars at point of shipment.

Specifications.—This proposal includes one steam-turbine generating unit, 45,000-kw. continuous capacity.

RATING

Cycles	Number of phases	Type	Poles	Rated kilowatts capacity at 90 per cent power factor	Revolutions per minute	Volts	Amperes, per phase at 90 per cent power factor	Excitation at 250 volts
60	3	X	6	45,000	1,200	12,200	2,370	175 kw.

The generator has a continuous output of 50,000 kva. or an actual energy output of 45,000 kw. at 90 per cent power factor.

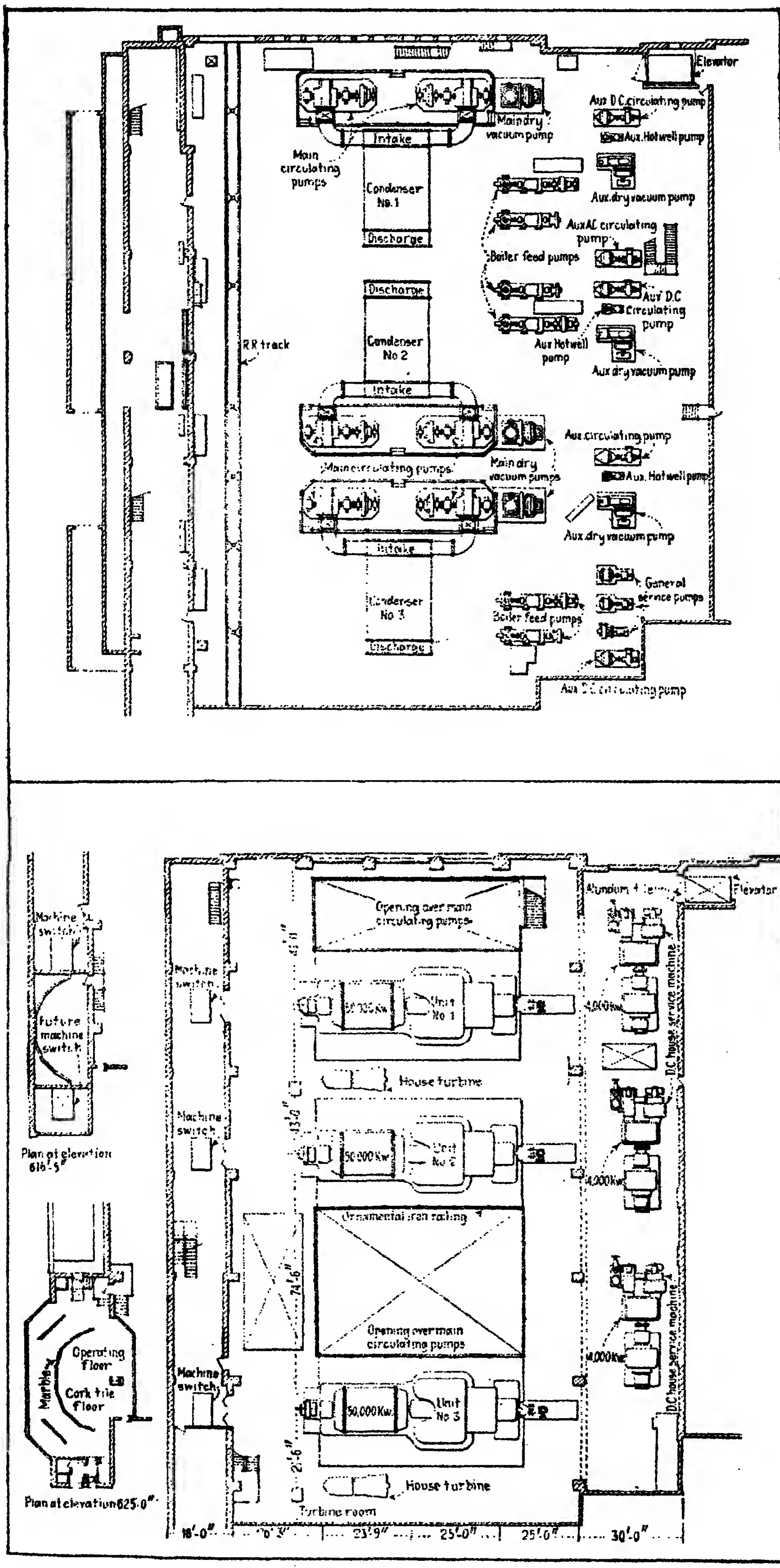

FIG. 116.—Floor plan of main units and auxiliaries of the Trenton Channel station of the Detroit Edison Company.

The maximum temperature of the generator armature at 50,000-kva. load and 90 per cent power factor will not exceed 100°C. provided the temperature of cooling air entering the generator does not exceed 40°C. The maximum total temperature of the revolving field, under the foregoing condition, will not exceed 135°C. The methods of determining temperatures, and the correction factors employed, are in accordance with the Standardization Rules of the A.I.E.E.

The armature will be subjected to an insulation test of 23,000 volts, and the field will be subjected to an insulation test of 2,500 volts at the factory before shipment. The insulation tests will be made by applying an alternating current between the windings and cores for one (1) minute.

The generator will be provided with suitable intake through which air will be drawn and forced through the laminations of the stator, and out through opening provided for the purpose. The arrangement of the station must be such that the generator will have an ample supply of cool, clear air. If air is supplied through a duct, such duct shall be designed to provide approximately 85,000 cu. ft. of air per minute for each machine.

The steam consumption in pounds per kilowatt-hour under conditions stated will be not more than the following:

Kilowatt Output of Generator	Steam pressure at throttle (gage)......... 225 lb. Steam quality at throttle (superheat)...... 225°F. Back pressure in exhaust chamber of turbine not more than 0.1..................(inches absolute)
20,000	11.5
30,000	10.85
35,000	10.85
45,000	10.95

Steam consumption guarantees cover all leakages and losses in the turbine and generator, including energy required in the field rheostat for excitation, and power required for ventilation.

Approximate Dimensions		Approximate Weigh	
Length overall..	65 ft. (over exciter)	Net................	1,000,000 lb.
Width.........	22 ft.	Shipping...........	1,000,000 lb.
Height........	17 ft.		

Shipment to be as follows: Twelve to thirteen (12 to 13) months from receipt of order and complete information at the factory. The purchaser will provide the company with all necessary information regarding local condition affecting the design and line-up of the apparatus, and the shipment specified is contingent upon the prompt furnishing of such information. The company will pay all transportation charges on the apparatus covered by this proposal, from the point of shipment to within reach of crane in purchaser's power house.

The turbine and generator connected herewith will operate at rated capacity without undue noise or vibration. The variation in speed will not exceed 2 per cent for a change in load of one-half the rated load.

The company will furnish a competent foreman and all common labor necessary for installing, starting and placing in good operating condition the turbines covered by this proposal on foundation in purchaser's power house. The purchaser will provide: (1) a suitable crane, with operator and power, capable of handling the heaviest piece; (2) oil, supplies, station operating force and steam, for starting and preliminary runs; (3) the necessary openings in the power house walls and further unobstructed access to foundations; (4) any runways, timber, blocking, etc., which may be necessary for the erection of the machine, or the reinforcement of weak floors or other

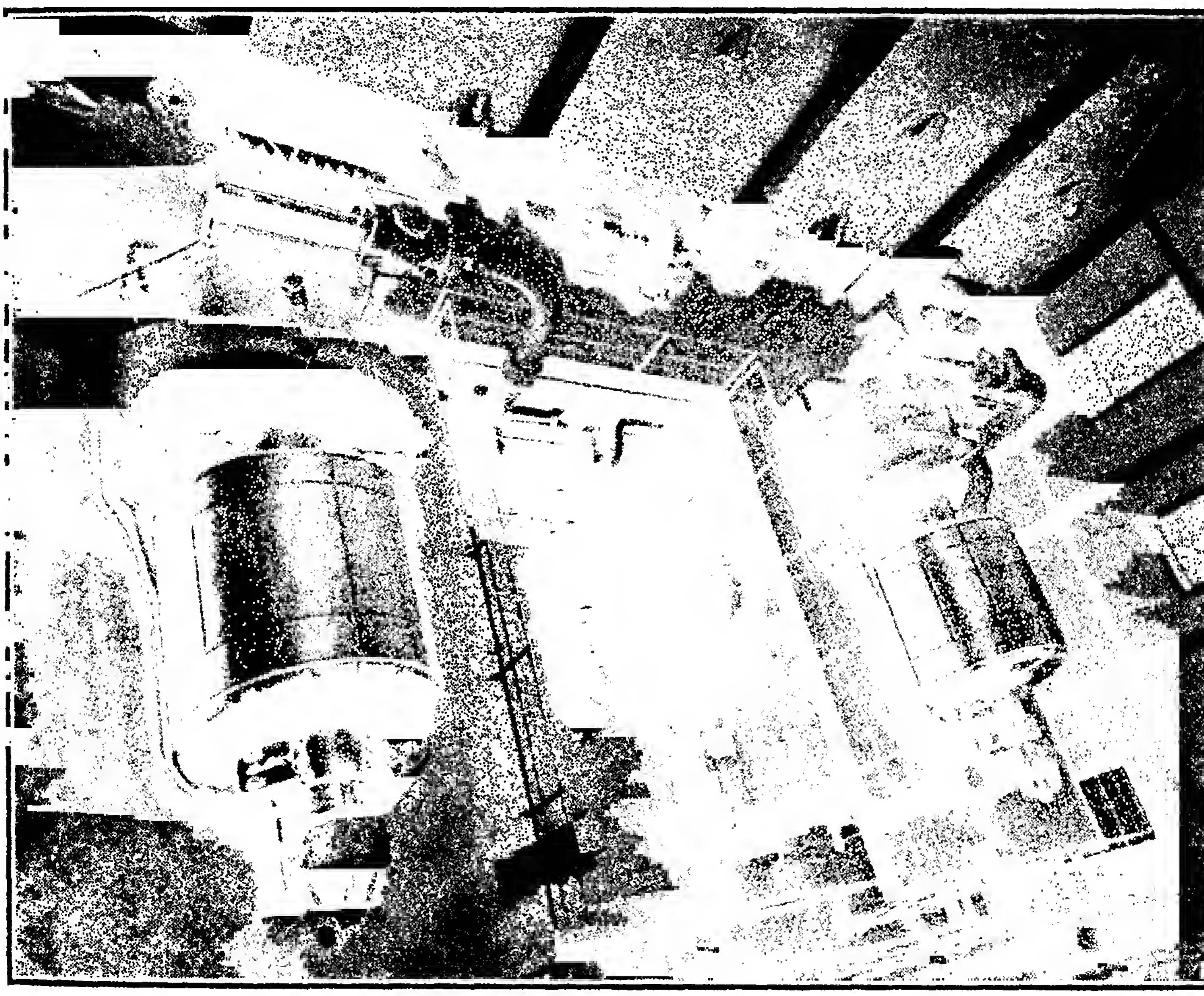

Fig. 117.—Two turbo-generators in operation showing island construction. Montvale station of Eastern Connecticut Power Company.

modifications of the purchaser's buildings or premises, as are necessary in erecting the apparatus covered by this contract; and will bring steam to the turbine and take steam from the exhaust opening.

The proposal includes throttle valve and screen in high-pressure steam pipe, speed indicator, steam gages, vacuum gage, oil-pressure gage, complete set of wrenches, speed-regulating governor, emergency stop and a suitable field rheostat for the generator. For supplying oil to the bearings and valve gear, the company will furnish a pump, geared to the turbine shaft.

Unless otherwise stated, this proposal *does not* include steam-generating apparatus, condensers, pumps (air, circulating or feed pumps), exciter, switchboard equipment or electric instruments, automatic relief valve con-

TABLE XXX.—TESTS ON WESTINGHOUSE 30,000-KW., 1,800-R.P.M. TURBINE GENERATOR[1]
(Tabulation of Data)

Test number	14	15	16	17	18
Approximate load, kilowatts	8,000	12,000	16,000	20,000	24,000
Duration, hours	1	1	1	1	1
Average pressures and temperatures					
Steam pressure at throttle, corrected, pounds per square inch	274.3	273.8	276.5	280.1	278.0
Steam pressure at throttle, absolute, pounds per square inch	288.7	288.2	290.9	294.5	292.5
Steam pressure at primary nozzle, corrected, pounds per square inch	129.7	183.3	241.7	277.2	274.8
Steam pressure at secondary nozzle, corrected, pounds per square inch	47.6	70.6	97.3	136.5	253.0
Steam pressure at tertiary nozzle, corrected, pounds per square inch	46.9	71.0	97.6	124.6	152.8
Steam pressure, 110-lb. zone, corrected, pounds per square inch	49.2	72.2	99.0	126.6	154.4
Steam pressure, 55-lb. zone, corrected, pounds per square inch	13.2	23.1	34.6	46.2	58.5
Vacuum, 200°F. zone, inches of mercury	14.5	9.05	2.85		
Vacuum, 140°F. zone, inches of mercury	25.31	24.04	22.56	21.01	19.51
Barometric pressure, inches of mercury	29.243	29.272	29.276	29.328	29.454
Barometric pressure, pounds per square inch	14.36	14.38	14.38	14.41	14.47
Vacuum, top of condenser, corrected to 30-in. barometer, inches of mercury	29.001	28.997	28.988	29.008	28.933
Absolute pressure top of condenser, inches of mercury	0.999	1.003	1.012	0.992	1.067
Temperature of emergent stem, degrees Fahrenheit	98.0	97.0	90.0	85.1	97.5
Temperature of steam at throttle, corrected, degrees Fahrenheit	741.5	728.4	750.1	739.9	733.6
Temperature of steam at throttle (bleed), corrected, degrees Fahrenheit	737.2	725.2	741.7	731.0	723.9
Temperature of saturation at throttle pressure, degrees Fahrenheit	414.0	413.8	414.7	415.8	415.2
Temperature of steam entering condenser, degrees Fahrenheit	73.7	74.0	74.8	74.9	77.4
Temperature of circulating water at condenser inlet, degrees Fahrenheit	36	38	38	42	40
Temperature of circulating water at condenser first pass, degrees Fahrenheit	36.4	38	40	46	44
Temperature of circulating water at condenser outlet, degrees Fahrenheit	46.6	50	51.4	56	55.4
Temperature of condensate, degrees Fahrenheit	73.3	74.2	74.0	71.5	70.3
Temperature in turbine-impulse stage, degrees Fahrenheit	564.3	564.0	588.9	603.7	628.8
Temperature of emergent stem, degrees Fahrenheit	....	177	194.7	196.9	206.5
Temperature in impulse stage, corrected, degrees Fahrenheit	572.3	572.0	579.0	613.5	639.9

Temperature in 55-lb zone, corrected, degrees Fahrenheit			139.0	179.6	198.8
Temperature in 200° zone, corrected, degrees Fahrenheit	211.5	277.9	299.9	377.4	426.5
Steam at throttle, superheat, degrees Fahrenheit	327.5	314.6	335.4	324.1	318.4
Total condensate, pounds	87,431	119,279	151,178	191,356	229,222
Leakage correction, pounds	90	90	90	90	90
Condensate per hour, corrected, pounds	87,341	119,189	151,088	191,266	229,132
Average kilowatt	8,286	11,991	16,339	20,275	24,072
Correction for vacuum, per cent	0.01	0.03	0.10	0.03	−0.24
Correction for superheat above 246°F. (1 per cent for 25°)	3.66	3.15	3.98	3.52	3.30
Correction for pressure above 275 lb. (1 per cent for 25 lb.)		.	. .	0.23	0.14
Correction for power factor, 100 per cent instead of 80	0.2	0.3	0.3	0.5	
Correction, total	3.87	3.42	4.18	4.28	3.20
Water rate—corrected—average	10.05	10.28	9.83	9.81	9.82
Water rate guarantee	11.25	10.25	10.0	10.15	10.6
Total weight of water measured, pounds	87,431	119,279	151,178	191,356	229,222

[1] N.E.L.A. Prime Movers Committee, 1925.

necting turbine to atmospheric exhaust, wiring or piping, other than that which is supported by and forms a part of the turbine structure.

Should tests be made to determine whether the performance of the turbine is in accordance with these specifications, such tests will be made at the expense and under the direction of the purchaser, and within three (3) months from the date of starting the apparatus. The conditions of test, instruments to be used, etc., will be mutually agreed upon, and the company

Fig. 118.—Westport station of the Consolidated Gas, Electric Light and Power Company of Baltimore. Note stage bleeding and feed-water heaters and the use of low voltage for auxiliary control.

shall have the privilege of being represented at such tests. The company reserves the right upon the notice from the purchaser to inspect the turbine prior to tests, to determine whether it is in normal condition. Foundations with foundation bolts are to be furnished by the purchaser.

In case of failure of the company for any reason to fulfil its guarantee, it is agreed that the company may remove and reclaim said apparatus at its

own expense, and repay the purchaser in full of all liability hereunder any sums which may have been paid by the purchaser on account of the purchase price herein named.

An extra charge will be made for iron oil barrels, carboys and wooden reels if used in shipping, but full credit will be given when returned to the factory or other point as may be designated by the company, in good condition, freight prepaid.

Price...
....

Payable as follows:

50 per cent cash, payable on receipt of bill of lading

50 per cent upon completion and starting.

Pro rata payments shall be made as shipments are made. In case shipments shall be delayed by the purchaser, invoices shall be rendered for material which the company is prepared to ship and payment shall be made in accordance with the above terms, such payments to date from date of such invoices; and in case the work shall be delayed by the purchaser, progress payments shall be made based on the contract price and per cent of completion in accordance with the above terms, such payments to date from date of invoice. It is agreed, however, that such payments shall be considered as advance payments only, and shall not discharge the purchaser from the obligations of this contract.

The title and the right of possession of the apparatus and material herein sold shall remain with the company and such apparatus and material shall remain personal property until all payments hereunder (including deferred payments whether evidenced by notes or otherwise) shall have been made in full in cash and the purchaser agrees to do all acts necessary to perfect and maintain such right and title in the company.

A copy of the specifications for turbine generators for the city of Detroit[1] contains some information of interest as to data on several turbine units and the forms used in competitive bidding.

Extent of Work.—The following work is not to be included as a part of that covered by these specifications:

1. Foundations and supporting structures.
2. External piping connections not a part of the machines.
3. Condenser with connection to turbine exhaust.
4. Oil filters and purifiers.
5. Air ducts, washers and filters for air supply to generator.

All other work, including all labor, materials, equipment and accessories further mentioned or necessary for constructing and installing the turbine-generator units hereinafter specified shall be done as a part of the work covered by these specifications.

Number Required.—Three or four units shall be furnished at the option of the commission.

[1] *Power*, Vol. 58, No. 22.

Table XXXI.—Schedule of Turbine Bids

(Morrell Street Plant, Public Lighting Commission, City of Detroit)

I. Bidder	Allis-Chalmers Mfg. Co.		General Electric Co.	General Electric Co.	Westinghouse E. & M.
II. Address	Milwaukee, Wis.		Schenectady, N. Y.	Schenectady, N. Y.	East Pittsburgh, Pa.
III. Price, 3 units	$939,000	Tolerance,	$969,000	$943,500	$945,900
IV. Price, 4 units	$1,247,000	Per Cent	$1,292,000	$1,258,000	$1,254,000
1. Delivery time, weeks	80	−5	1st 61 2nd 65 3rd 69 4th 74	1st 61 2nd 65 3rd 69 4th 74	1st 52 2nd 56 3rd 61 4th 65
2. Erection time, weeks	24	−5	8 to 10	8 to 10	8
3. Net weight, turbine, pounds	426,000	±3	294,000	282,000	534,000
4. Net weight generator, pounds	204,000	±3	185,000	185,000	239,000
5. Net weight complete unit, pounds	630,000	±3	525,000	515,000	773,000
6. Steam cons. without excitation, pounds per kilowatt-hour with steam at 300 lb. per square inch 200°F. superheat and 1-in. absolute back pressure when generator output at 0.80 power factor is: 10,000 kw.	10.67	0	11.10	11.15	10.70
15,000 kw.	10.17	0	10.40	10.50	10.15
most economical	10.09	0	10.25	10.45	10.05
20,000 kw.	10.27	0	10.40	10.50	10.20
7. Maximum load steam at 250 lb. per square inch, 150° superheat 1.5-in. absolute back pressure, 0.80 power factor	20,000	±2	20,000	20,000	19,500
8. Maximum blade tip speed, feet per second	660		880	880	865
9. Maximum stresses, disk, pounds per square inch	23,500		23,000	24,000	Mean stresses in spindle body 12,000
10. Temperature rise bearings continuous operation, degrees Fahrenheit.	125 to 145°F. maximum		To 145.4° based on room at 104°F.[a]	To 145.4° based on room at 104°F.[a]	To 130°F. maximum
11. Capacity of oiling system, gallons	1,400	±5	950	700	1,050
12. Oil circulated, gallons per minute	150	±5	100	170	125
13. Speed regulator, 0 to full load, per cent	2	±5	4	4	3
14. Generator temperature, degree Centigrade with 25,000 kva. continuous operation inlet air 40°C.: stator	100	A.I.E.E.	100	100	125
rotor	125	A.I.E.E.	135	135	150
15. Voltage regulator, 0 to full load, 0.80	40	±5	30	30	38
16. Excitation, 20,000 kw. at 0.8 power factor	80	0	100	100	100
Power kilowatt, 25,000 kw. at 1.0 power factor	62	0	75	75	75
17. Rated capacity exciter, kilowatt			120	120	125
18. Air required, generator, cubic feet per minute	70,000	0	60,000	60,000	65,000
19. Generator reactance, per cent	16	±10	13	13	13
20. Turbine speed, revolutions per minute	1,800		1,800	1,800	1,800

[a] Temperature rise given as 41.4°F.

Capacity.—Each unit shall have a normal rated capacity of 20,000 kw. at 80 per cent power factor.

Description of Unit.—Each unit shall consist of a horizontal steam turbine direct connected to an alternating-current generator with direct-connected exciter.

Turbines.—The turbines shall be designed for a normal steam pressure at the throttle of 315 lb. per square inch absolute, 200°F. of superheat and an absolute back pressure of 1½ in. of mercury. Under these conditions they shall operate at maximum economy with a steam consumption not exceeding 10.5 lb. per kilowatt-hour when the load on each generator is approximately 17,000 kw. at 80 per cent power factor.

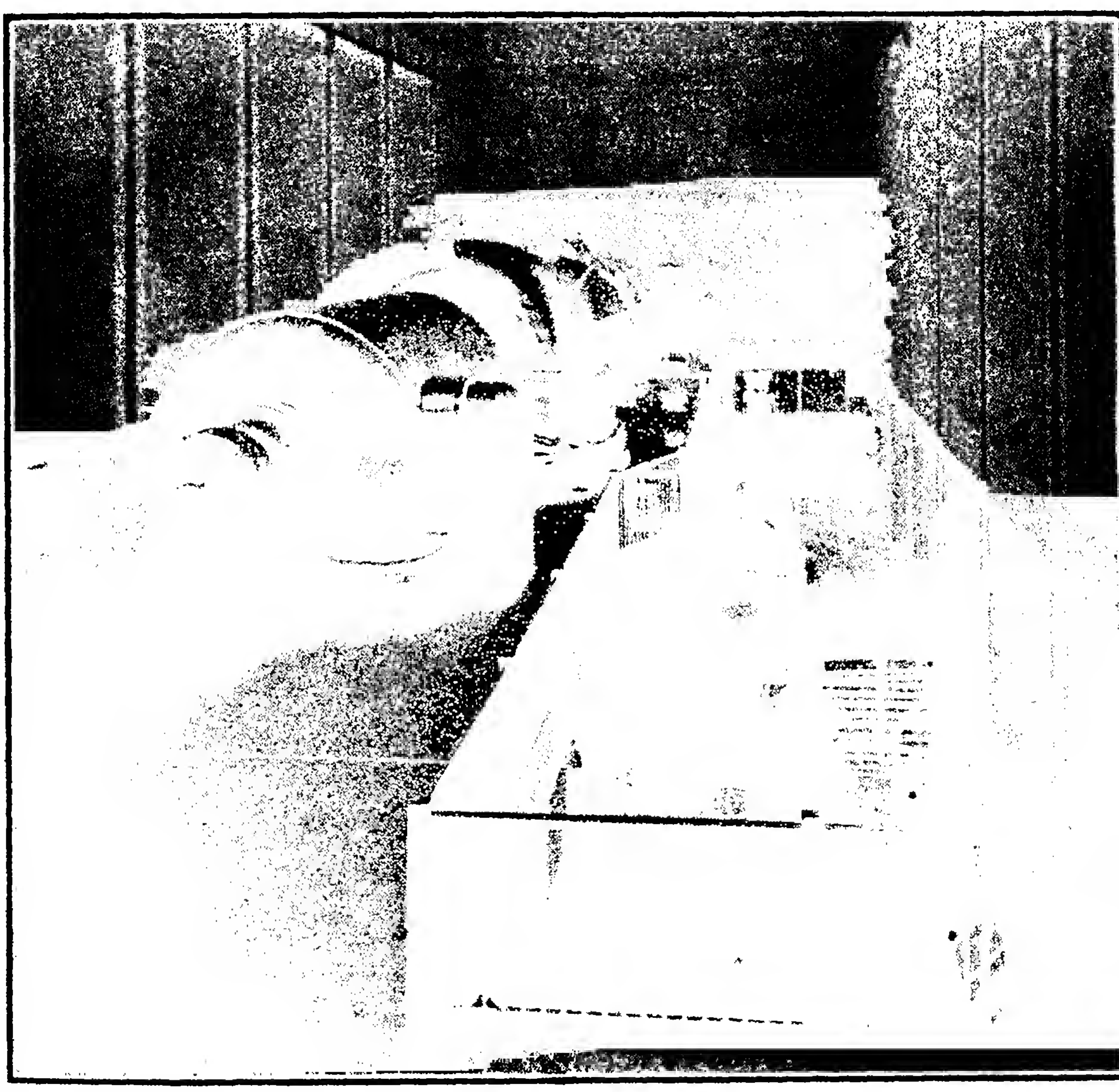

FIG. 119.—Turbine room in the Cahokia station of the Union Electric Light and Power Company, St. Louis.

Each turbine shall be capable, by governor control only, of driving the generator when the load is 25,000 kw. at unity power factor with steam pressure, superheat and back pressure as stated above.

Each turbine shall be provided with extraction nozzles located, in so far as limitations of design and construction will permit, to supply steam in such quantities and at such pressures as may be required to maintain the heat balance of the plant. The following is an approximation of these requirements:

Nozzle No.	Absolute pressure, pounds per square inch	Steam bled, pounds per hour
1	170	13,000
2	34	10,000
3	4	11,000

All parts of the turbines subject to contact with steam having a temperature above 500°F. shall be of steel or other high-temperature steam-resisting material. The turbines shall be capable of withstanding an initial steam pressure of 365 lb. per square inch absolute and a total temperature of 700°F. without injury to any of their parts.

Generators.—The generators shall be three-phase, 60-cycle, 13,200-volt, star-connected machines. They shall be wound for excitation at 240 volts at maximum load. All leads shall be brought to the outside of the machines to permit applying differential protection.

Rotor fans shall be capable within limitations of design of producing sufficient static pressure to circulate the air supplied to the generators through the duct system.

Accessories.—Each unit shall be provided with throttle valve, generator and exciter field rheostats, vibration tachometer and generator temperature indicators.

Rheostats shall be equipped with 125-volt direct-current motor-operating devices. Exciter field rheostats shall be of sufficient capacity to reduce the voltage 80 per cent below normal.

One set of wrenches and special tools required by peculiarities of design shall be furnished.

Delivery and Erection.—The units shall be delivered and completely erected ready for external piping and electrical connections.

Proposal Form to Be Copied by Bidder

(Date).............192.....

(Name of Bidder)...

Original or Duplicate Proposal for Turbine-generator Units to the Public Lighting Commission of the City of Detroit

I. The undersigned proposes and agrees to contract with the Public Lighting Commission of the City of Detroit, in the form of contract accompanying the specifications, to furnish all the labor, materials and equipment, and perform all the work called for by the specifications and drawings which they mention, prepared by Smith, Hinchman & Grylls, 800 Marquette Building, Detroit, Mich., entitled: "Specifications for Machinery and Equipment" for Morrell Street Plant of the Public Lighting Commission of the City of Detroit, Section E, "Specifications for Turbine-generator Units," and agrees to accept as payment therefor the sum of

....................................$..........for three units;

....................................$..........for four units.

II. The undersigned further proposes that the execution of his work and the character and performance of the completed work will conform to the following, and guarantees that the deviation therefrom will not exceed the tolerances which he has stated:

		Per Cent Tolerance
1. Time within which complete shipment will be made after entering into contract, weeks	....	....
2. Time within which erection will be completed after making shipment, weeks	....	....
3. Net weight of turbine, pounds	....	....
4. Net weight of generator, pounds	....	....
5. Net weight of complete unit, pounds	....	....
6. Steam consumption of unit without extraction in pounds per kilowatt-hour with 300 lb. per square inch, 200°F. superheat, at throttle and 1-in. absolute back pressure when generator output at 0.8 power factor is:		
10,000 kw	....	....
15,000 kw	....	....
kw. (most economical)	....	....
20,000 kw	....	....
(Submit curves based on 0.6-, 1.0- and 1.5-in. back pressure.)		
7. Load that unit will carry when steam at throttle drops to 250 lb. per square inch, 150°F. superheat and back pressure to 1½ in. absolute, kilowatt at 0.8 power factor	....	....
8. Maximum tip speed of blading, feet per second.	....	....
9. Maximum stresses in disks at normal speed, pounds per square inch	....	....
10. Temperature rise of bearings with unit in continuous operation, degrees Fahrenheit	....	....
11. Oil-holding capacity of oiling system, gallons ...	....	....
12. Oil circulated, gallons per minute	....	....
13. Speed regulation of turbine, no load to full load, per cent	....	....
14. Generator temperature (degrees Centigrade) including "conventional allowance" with 25,000-kva. continuous load and 40°C. inlet air:		
Stator (method.......)	....	....
Rotor (method.......)	....	....
15. Voltage regulation of generator no load to full load at 0.8 power factor, per cent	....	....
16. Power required for excitation at following loads, kilowatt:		
20,000 kw. at 0.8 power factor	....	....
25,000 kw. at 1.0 power factor	....	....

		Per Cent Tolerance
17. Rated capacity of exciter, kilowatt............	....	....
18. Air required by generator, cubic feet per minute	....	....
19. Inherent reactance of generators, per cent......	....	....
20. List of spare parts and number which bidder recommends to be carried and price of each at which he will furnish and deliver them with the turbine units:		
Name of Part	Number	Price

III. If this proposal shall be accepted by the Public Lighting Commission and the undersigned shall fail to contract as aforesaid and to furnish the required bonds within 10 days, not including Sundays, from date of serving written notice from the engineer that the contract is ready for signature, then the undersigned shall be considered to have abandoned the contract, and the certified check accompanying this proposal, for the sum required by the notice to bidders, shall become the property of the Public Lighting Commission. If the undersigned enters into the contract in accordance with this proposal, or if his proposal is rejected, then the accompanying check shall be returned to the undersigned.

IV. Signed and sealed this..........day of..............192:........

Present Trends.—The desire of turbine manufacturers at present is to produce very large, reliable and highly economical turbo-generators at a minimum cost. Increase in size of units is necessary to serve the loads that now exist and the recent purchase of a 208,000 kva. unit by the State Line Generating Company of Chicago marks the largest unit on order. Plans have been made for still larger units and there seems to be no definite limitation in size. The larger the unit the less the total power station cost per unit of capacity within limits and the less the cost of the turbo-generator per unit of capacity.

To secure high economy in turbines, pressure compounding must be used and an appropriate ratio of mean blade velocity to steam jet velocity must be maintained. Since the thermal efficiency depends on the temperature range, a large pressure range must be used and the expansion ratio in modern units is of the order of 1,500 to 1 with a temperature range of about 675°.

If the steam velocity is increased, the number of stages is decreased but the advantages of a large pressure range are lost and the efficiency of conversion of the steam energy into mechanical work in the nozzles and blading is decreased as the velocity is decreased. Also the stage efficiency of a turbine operating with saturated steam is less than that of one operating with super-

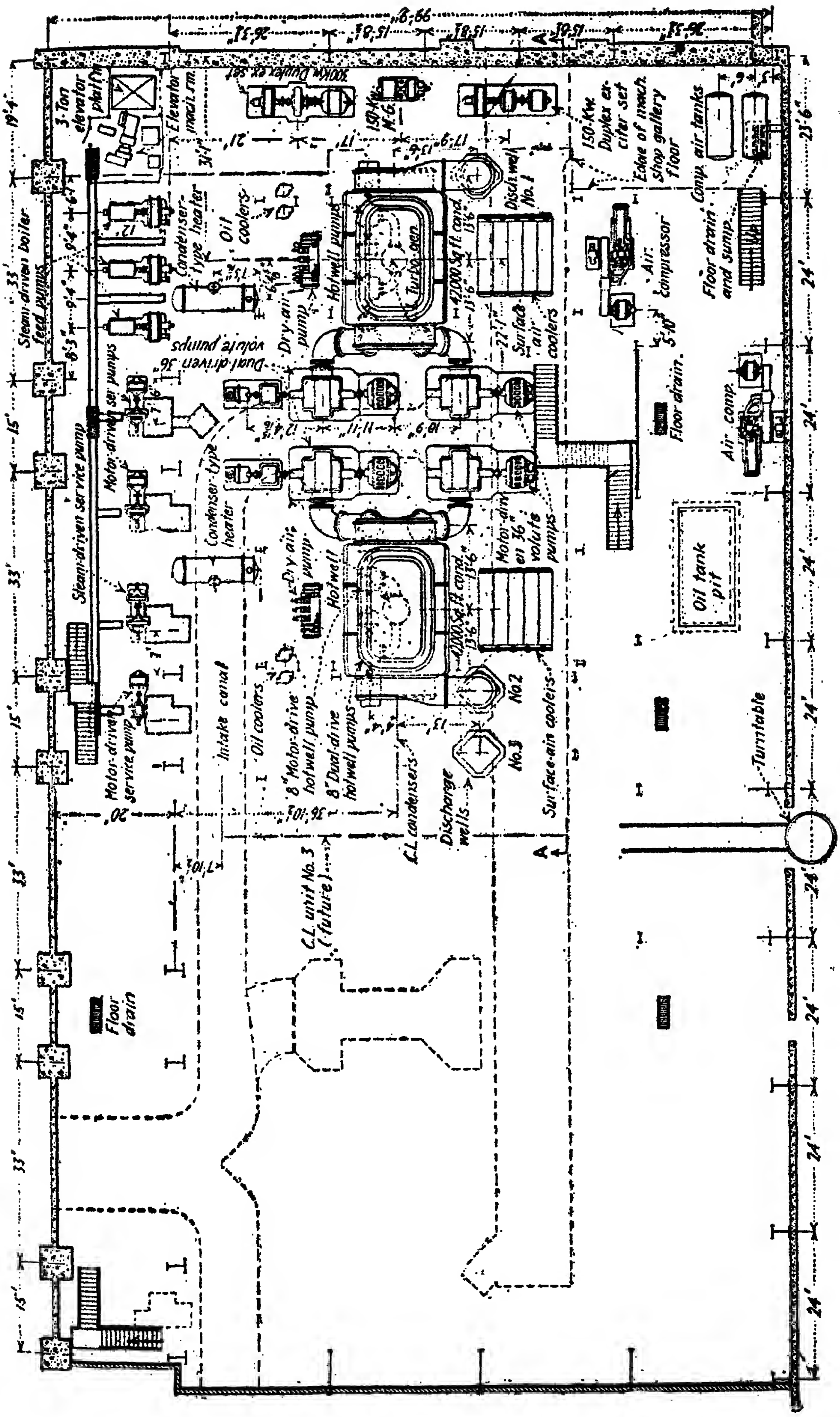

FIG. 120.—Plan of turbine room basement in Avon station of the Cleveland Electric Illuminating Company. 300,000 kw., ultimate rating.

heated steam so the effect of moisture and temperature on pressure compounding must be measured against the advantages of low steam velocity. Designers and builders are securing equally good thermal results from the impulse and reaction types of turbine by careful design to care for conditions.

The thermal value of the heat in the steam used in a turbine is increased by using extraction steam from successive stages, thus increasing the mean temperature of heat reception. The extracted steam has been expanded while doing work in the main turbine until its temperature has dropped to a value desired for feed-water heating. The work obtained from the extracted steam

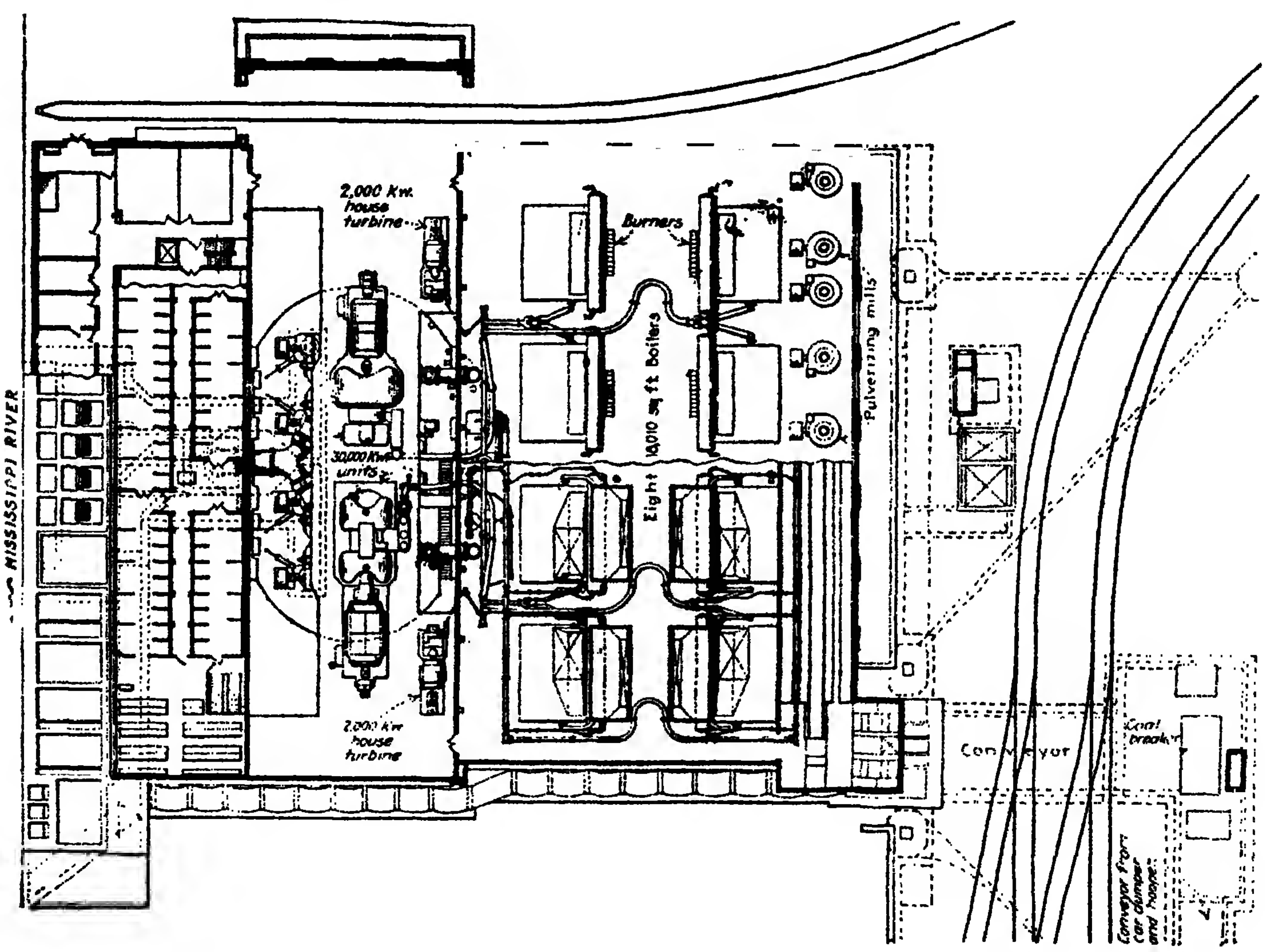

Fig. 121.—Floor plan of the first section of the Cahokia station of the Union Electric Light and Power Company, St. Louis.

is done at the expense of additional heat equal to the work done or at 100 per cent efficiency. The objection to this practice is that the piping is increased and becomes complicated if a sufficient number of extraction points and corresponding feed-water heaters are used to approximate the thermo-dynamically reversible process, but even with two to four extraction points very considerable economies are obtained. A second development is to reheat the steam during the pressure compounding process. This involves the use of multiple-cylinder turbines and some form

of reheater. The reheater may be a separately fired reheater or one that utilizes superheated steam from the boiler. The thermal advantages of this practice are not great, but the mechanical features of operation are improved because of the better conversion ratio obtained with high-temperature steam. But the complication and cost of reheating are severe handicaps to its general adoption for small units.

The designers of turbines attempt to fix the velocity ratio in successive stages, as this determines the efficiency. The areas of blade passages increase in the stages to maintain a proper ratio

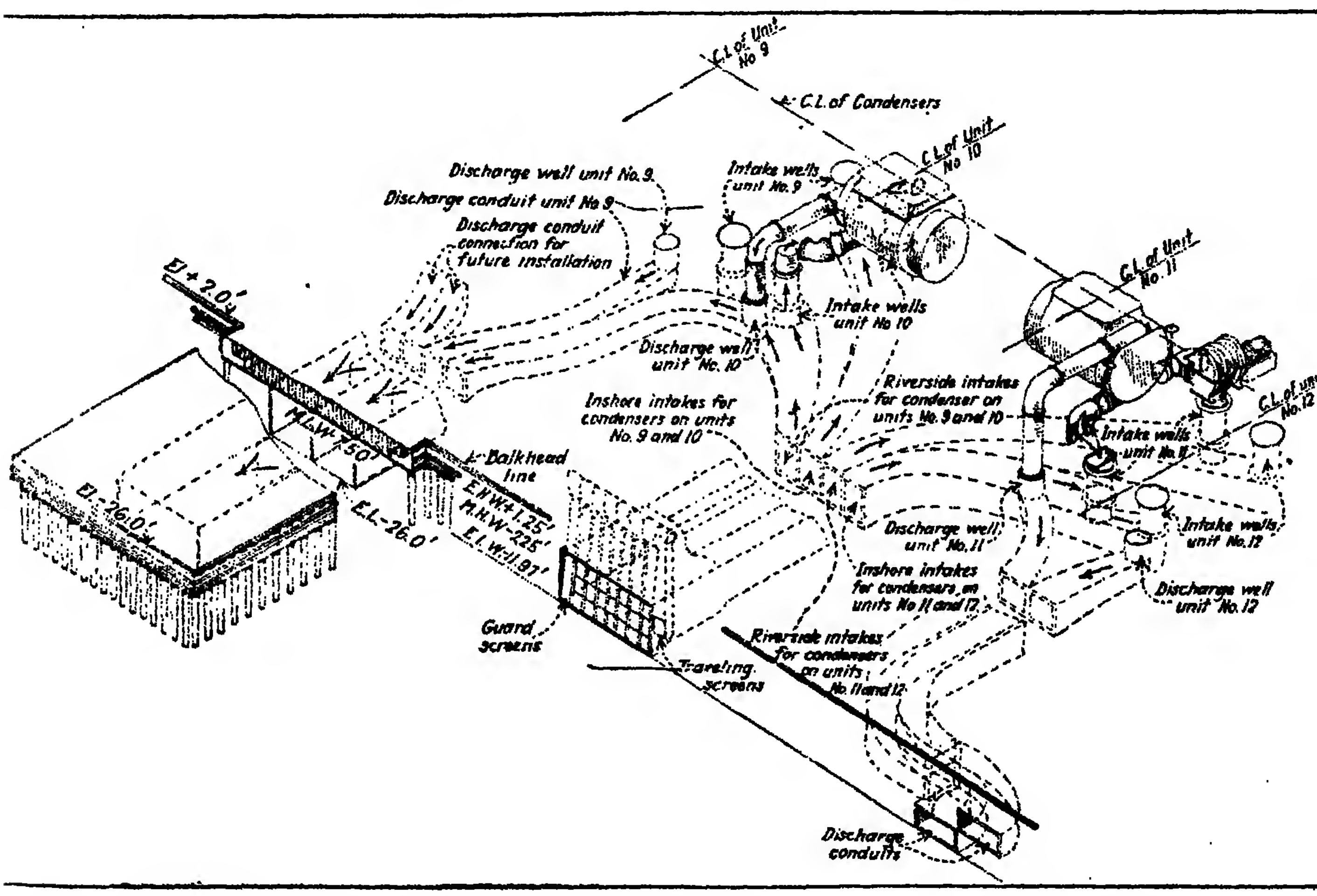

FIG. 122.—Circulating water arrangement for the Richmond station of the Philadelphia Electric Company.

between blade velocity and steam velocity and the axial component of the steam is carried without appreciable loss to the exhaust. Here an unavoidable loss is encountered, since with the low pressures and the high peripheral speeds in the last stages an exhaust blade area for the proper velocity ratio gives an energy loss in the exhaust steam which is appreciable. Thus the exhaust end of a turbine received separate design treatment to limit the leaving loss or the energy loss in the issuing steam.

One method is to use divided flow, the steam entering at the middle of a low-pressure cylinder and flowing in each direction to the exhaust. This requires two exhaust pipes and often two condensers. Another method is to use divided flow for only

the last row or few rows of blades, special passages conducting the steam to the divided-flow blades from the preceding stages. The exhaust end of the Baumann type causes the steam to flow through inner annuli of preceding blade rings whose vanes have been shaped to reduce resistance to a minimum. This avoids the use of special passages. Still other designs increase the blade height by making the blades of the last stages of varying section and discharge angle to secure a greater length ratio. The use of a separate low-speed turbine of large diameter for the final stages of expansion is a simple solution to the exhaust-loss problem if no limitation is placed on the diameter of the exhaust end or upon the speed.

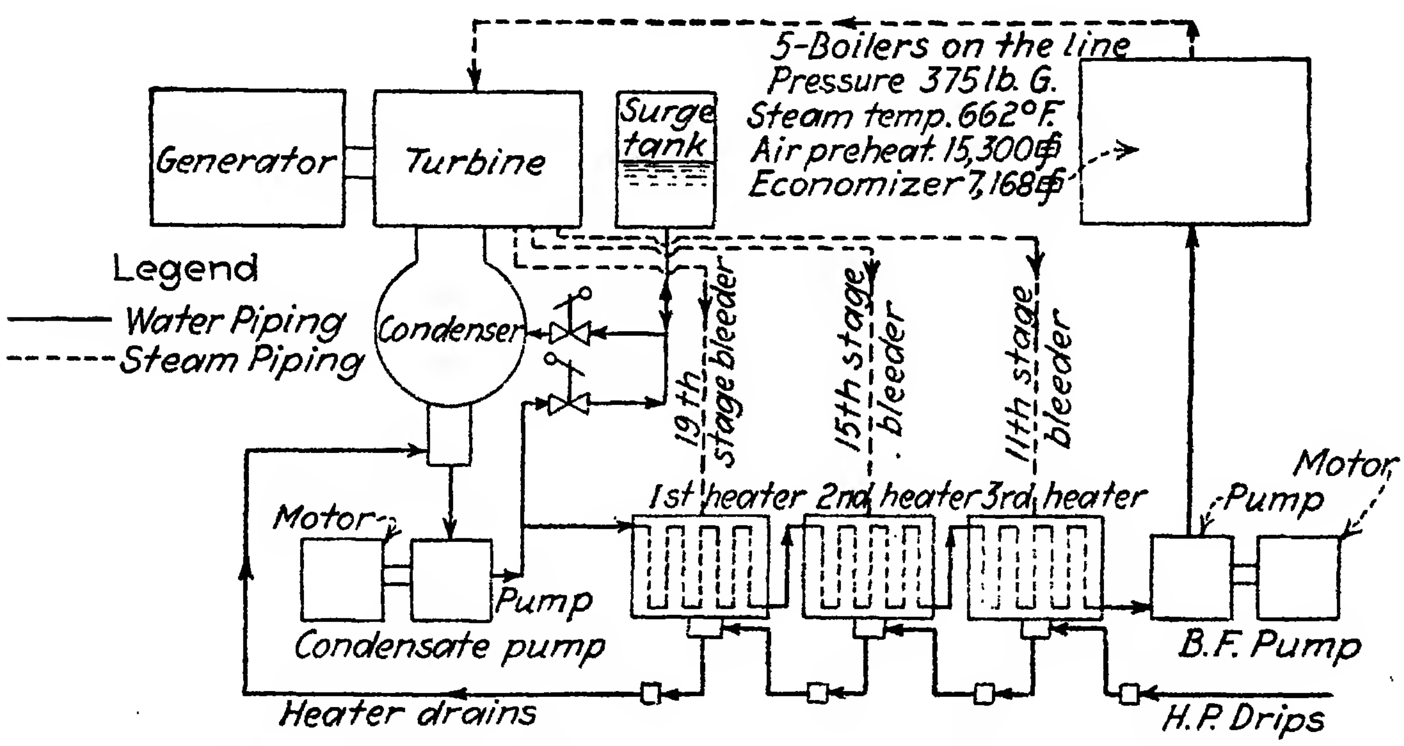

FIG. 123.—Auxiliary arrangements in Richmond station of the Philadelphia Electric Company.

Lubrication.—Turbine lubrication is a very important consideration and the N.E.L.A. Prime Movers Committee in 1921 proposed a specification for lubricants as follows:

General.—1. This specification covers the grades of petroleum oil intended for use in the lubrication of horizontal steam turbines provided with a circulating and forced-feed system.

2. The oil shall be a pure petroleum product, properly refined to make it suitable in every way for the uses hereinbefore specified; it shall be new oil made without the admixture of any fatty oils, resins, soaps or any other compounds not derived from crude petroleum.

3. These oils shall be supplied in three grades, known as Extra Light, Light and Medium. Except where otherwise noted, the same specifications apply to all three grades.

Properties and Tests.—4. All tests shall be made in accordance with the methods for test lubricants adopted by the Committee on Standardization

of Petroleum Specifications, published in *Bulletin* 5, by the U. S. Bureau of Mines, effective Dec. 29, 1920, except as hereinafter described under "Methods of Testing."

5. *Flash and Fire Points.*—The flash and fire points, open cup, shall have the following minimum values:

Grade	Flash, degrees Fahrenheit	Fire, degrees Fahrenheit
Extra Light	315	355
Light	325	365
Medium	335	380

6. *Viscosity.*—The viscosity, in seconds, Saybolt Universal, shall be as follows:

Grade	Limits at 100°F.	Minimum at 210°F.
Extra Light	140–160	40
Light	175–210	42
Medium	250–310	46

7. *Color.*—All oils covered by these specifications shall be perfectly limpid and transparent when examined at 77°F. in a layer 1¼ in. thick.

8. *Pour Test.*—The maximum pour test shall be 40°F.

9. *Acidity.*—Oils shall be absolutely free from mineral acid, and the organic acidity, expressed as the amount of potassium hydroxide required to neutralize 1 gram of the oil, shall not exceed 0.07 mg.

10. *Waters Carbonization.*—Carbonization shall not be greater than the following values:

Grade	Per Cent
Extra Light	0.50
Light	0.30
Medium	0.20

11. *Corrosion.*—A strip of polished copper immersed for 5 hr. in a sample of the oil kept in a bath of boiling water shall show no more than a faint discoloration for the depth to which it was immersed.

12. *Emulsifying Properties.*—When emulsified by the standard method of agitation, the rate of separation of the oil from the emulsion shall not be lower than shown in the following table:

Grade	Emulsifying liquid		
	Distilled water (demulsibility)	3 per cent salt solution	1 per cent NaOH solution
Extra Light..........	600	600	40
Light...............	400	400	40
Medium.............	300	300	40

13. *Distillation.*—When submitted to a fractional distillation test, at an absolute pressure of 1.5 to 5.0 mm. Hg, the lowest permissible initial boiling point, and the maximum per cent distillate, by volume, when distillation is carried to a temperature of 225°C. (437°F.), shall be as given in the following table:

Grade	Per cent distillate	Initial boiling point
Extra Light...........................	50	175°C. (347°F.)
Light..................................	30	185°C. (365°F.)
Medium...............................	15	200°C. (392°F.)

Methods of Testing. *Waters Carbonization.*—This test shall be made as directed in *Circular* 99 of the U. S. Bureau of Standards.

Corrosion Test.—Strips of No. 10 gage polished copper about 10 mm. wide and 125 mm. long are heated to a dull redness and inserted in a test-tube containing a few cubic centimeters of methanol or alcohol until cool, and then polished thoroughly with very fine sand paper.

Pour 100 c.c. of the oil to be tested into a 4-oz. sample bottle; insert the end of the copper strip into a split cork and push the cork firmly into the mouth of the bottle; place the bottle in the water bath so that the shoulder is just above the perforated cover; maintain the bath at the boiling point of water for 5 hr. without disturbing the bottle. It is preferable to carry out the test on each oil in duplicate. The number of tests which can be run at one time is limited only by the capacity of the bath.

Interpretation.—Darkening of the copper on the submerged surface indicates corrosion due to sulphur or a corrosive sulphur compound.

Diminution of the polish or the appearance of a dull reddish color on the submerged surface of the copper indicates corrosion due to acids or acid compounds. In extreme cases, some pitting of the surface may be observed.

Darkening or corrosion of the emergent surface indicates formation of vapors containing acid or sulphur compounds.

High-grade oils should leave on the copper no more than the faintest indication of the depth to which it was immersed.

Emulsifying Properties.—This test shall be made as directed in *Technologic Paper* 86, U. S. Bureau of Standards, when distilled water is used.

In the other two tests, 20 c.c. of oil shall be emulsified with 40 c.c. of the emulsifying solution and in other respects the tests shall be carried out exactly as in the test for demulsibility.

Distillation Test.—The apparatus and method of operation shall be similar to that in use at the U. S. Bureau of Standards, which is described as follows:

"The apparatus consists of a steel still having a 2½-liter capacity. The still head is connected with a vertical water-jacketed condenser which, in turn, leads to a receiver holding the graduated bottle or bottles. The whole

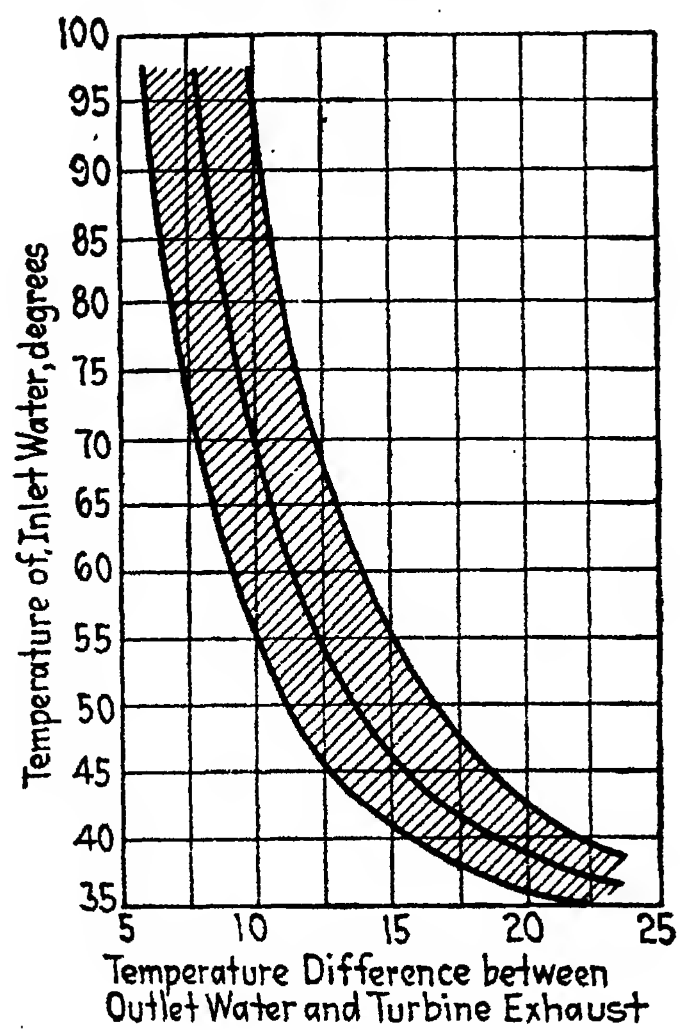

FIG. 124.—Operating results with large jet condenser.

Considerable data have been collected on the practical operating results with large jet condensers applied to turbines of 10,000 kw. or larger. The plot is made from some 300 readings showing terminal temperature differences between turbine exhaust and outlet water plotted against temperature of inlet water for readings of three-fourths to full load. The condensers upon which data were obtained operate in connection with the following turbines: three of 10,000-kw. capacity; four of 12,500-kw.; four of 20,000-kw.; and two of 45,000-kw. While there were great variations in some of the data submitted, the great majority of readings fell within the shaded area shown. Insufficient data were furnished for plotting loads other than three-fourths to full. (*N.E.L.A. Prime Movers Committee,* 1923.)

system is connected with a pump capable of maintaining a vacuum of 1.5 to 5.0 mm. of mercury, absolute pressure. For recording the pressure, a manometer is placed between the pump and the receiver. The temperature of the oil in the still is measured by a standardized thermometer. Violent boiling or bumping occurs in distillation under reduced pressure. At times, this bumping becomes so violent that unless special precautions are taken to prevent it, oil is carried over into the condenser, thus contaminating the distillate. This can be overcome by using conical screens attached to a steel rod suspended in the still head, and a steel baffle plate attached to the bottom of the still head.

"The still is charged with the oil under examination. Great care must be taken to have all connections and joints air tight to prevent oxidation of the oil, due to leakage. The pump is then started, and when the manometer indicates the desired pressure, the heat is applied. A ring type gas burner is used which is set low so that no fire touches the still bottom, thus preventing localized heating and consequent coking and cracking. When the first drop of distillate comes over, the temperature is read and recorded as the initial boiling point. The rate of distillation is easily controlled.

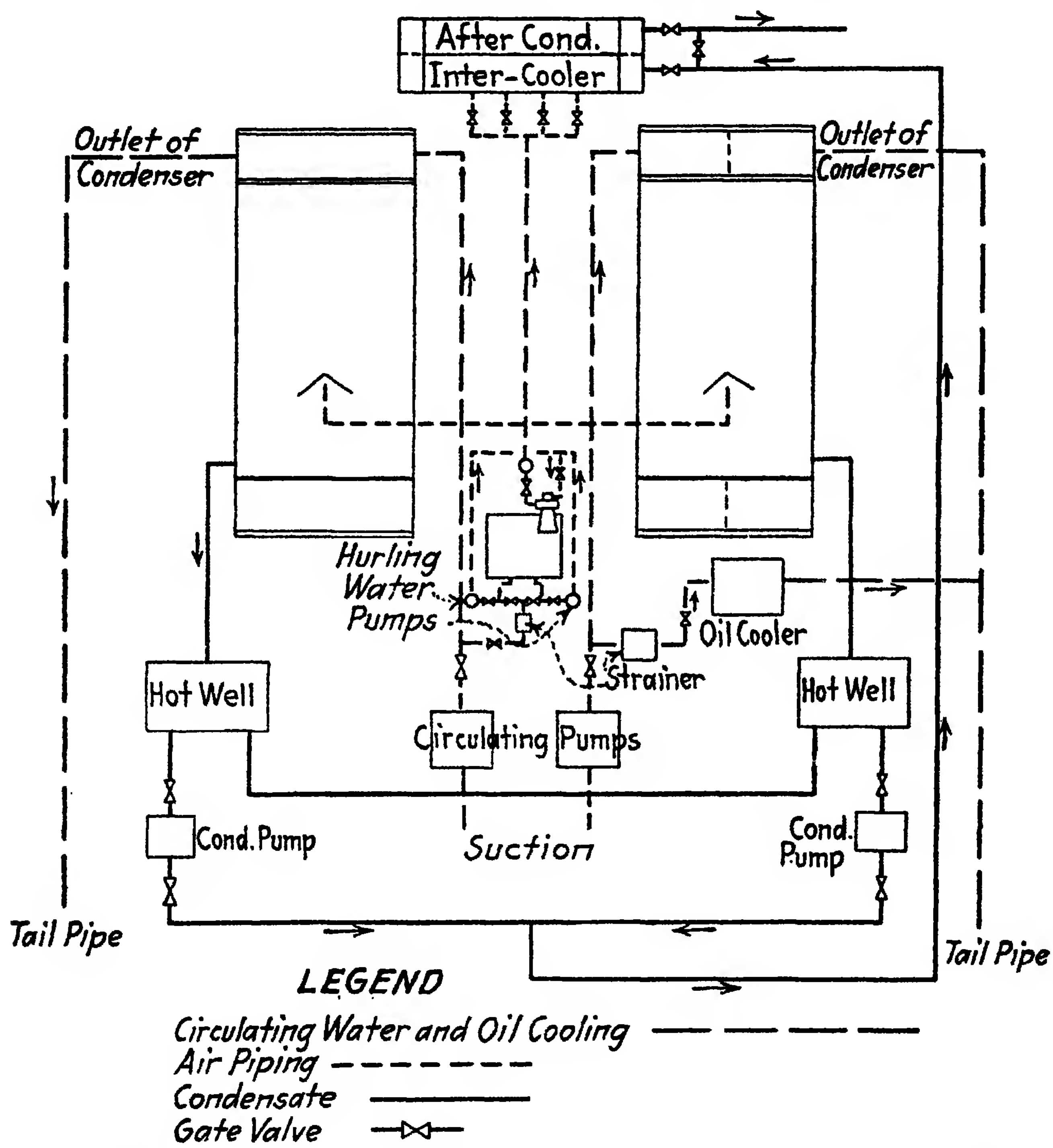

FIG. 125.—Diagram of condensing equipment for Crawford Avenue station of the Commonwealth Edison Company, Chicago. Unit 2.

"It was found that cracking occurs if distillation is carried above 300°C. (572°F.). The same per cent of distillate is obtained at 1.5 and 5.0 mm. pressure, with a lowering of but 2°C. in the boiling point at 1.5-mm. pressure."

Condensers.—A very important element in the economical operation of the steam units is the vacuum as is indicated by Fig. 115. Circulating water, in ample quantity, clean and of

an approximately constant temperature is almost unknown, and in addition the load on the units may vary. Summer and winter conditions, the cleanliness of the circulating water and the changing loads make it a difficult matter to control vacuum adequately. A condenser and circulating water supply sufficient to care for

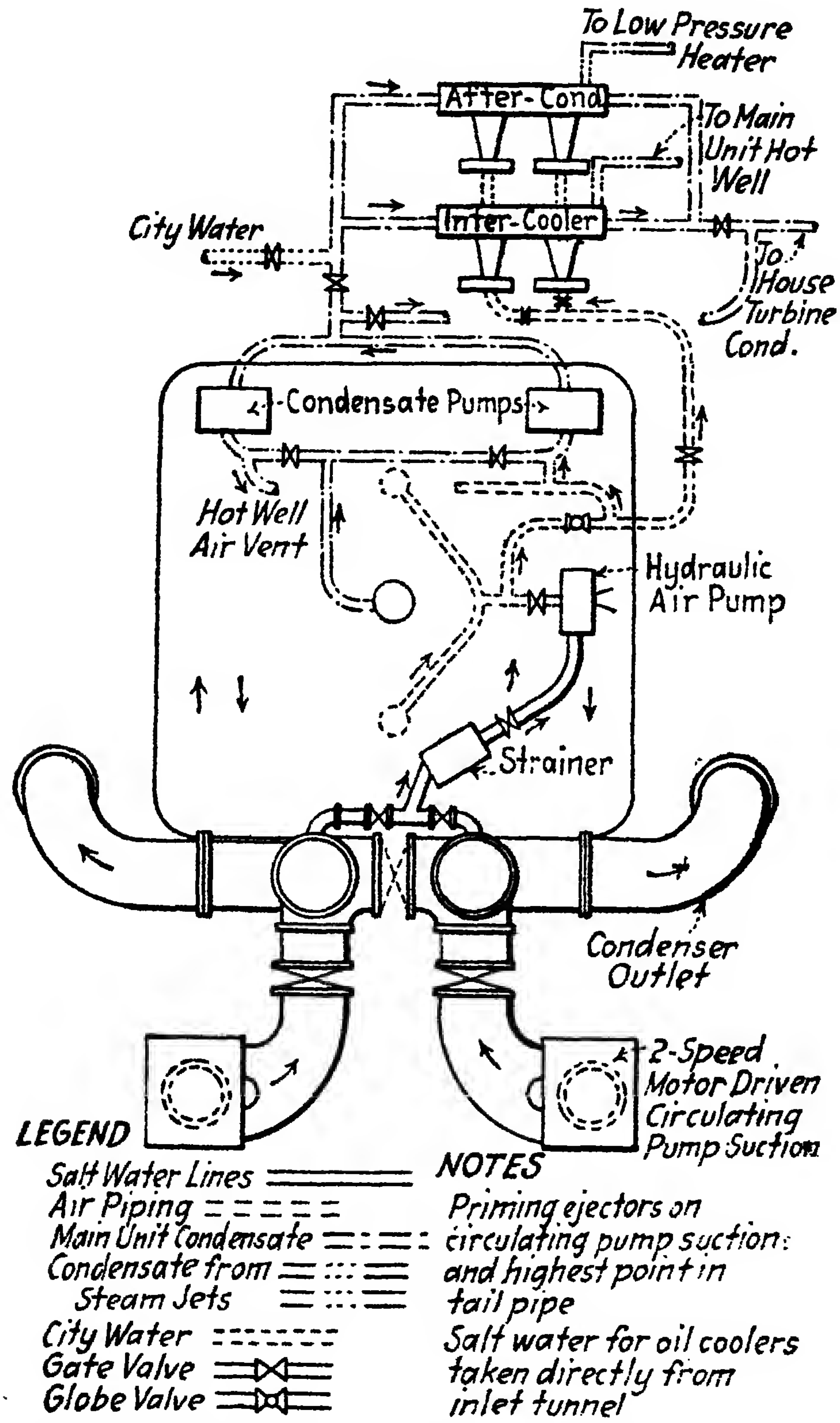

FIG. 126.—Arrangement of condensing equipment for the Hudson Avenue station of the Brooklyn Edison Company.

the worst condition in summer operation ties up a needless amount of equipment and capital under winter operating conditions. The use of duplicate pumps, variable-speed pumps and partitions in the condenser are methods used to better the operation under these conditions. The use of two pumps, one operating in

winter and both in summer with or without condenser partitions, affords a simple way of controlling the circulating water supply; the use of two pumps with variable-speed drive decreases the reliability of the supply and gives difficulty to motor designers

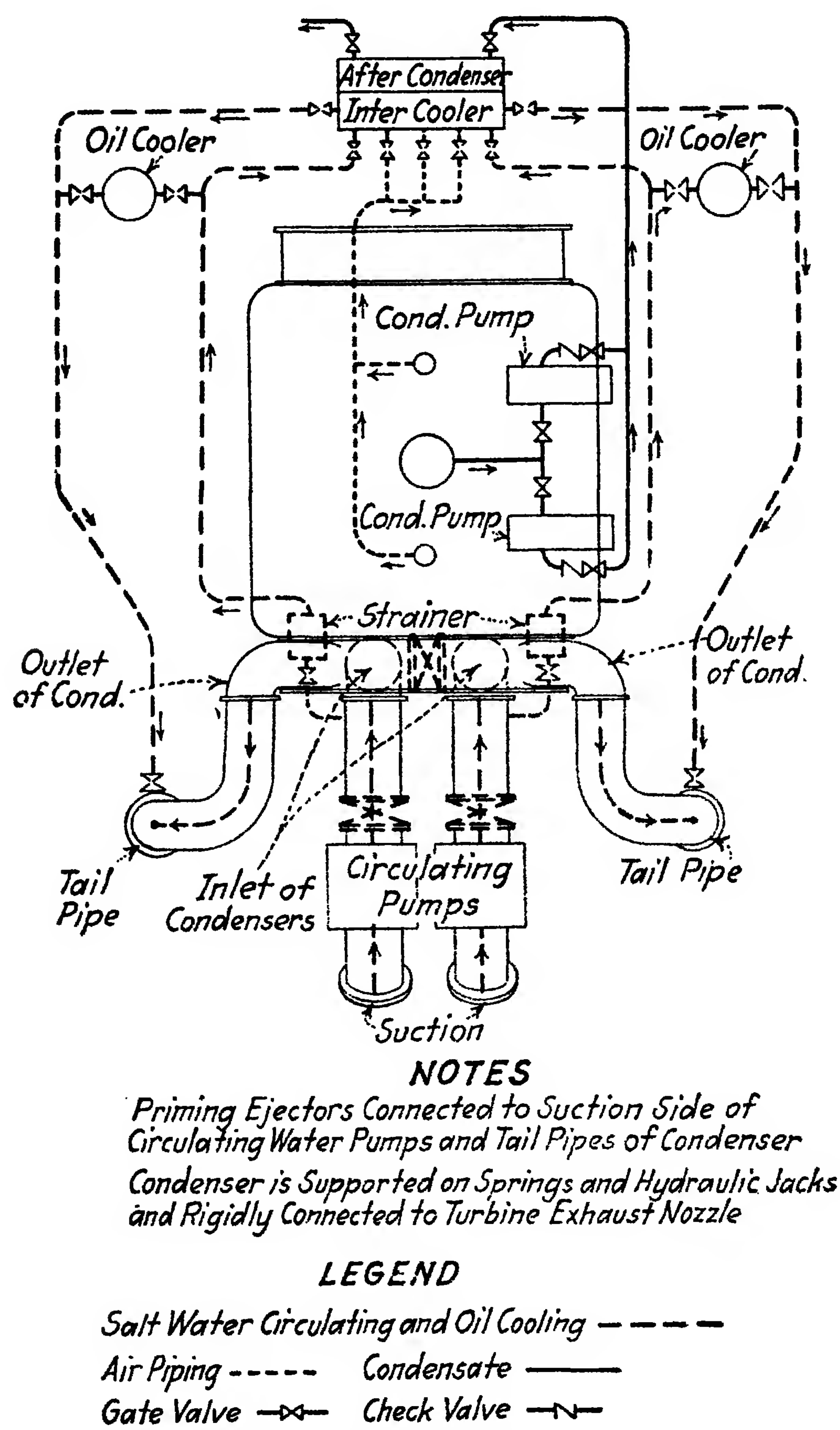

FIG. 127.—Condensing equipment in the Hell Gate station of the United Electric Light and Power Company, New York. Unit 7.

when alternating-current machines are used. Tests of a two-pump constant-speed installation on a 50,000-sq. ft. condenser having a partition give results shown in Table XXXII.

TABLE XXXII.—TESTS FOR DUPLICATE PUMPS ON A 50,000-SQ. FT. CONDENSER—CONSTANT SPEED[1]

	One pump	Two pumps
Pumps operating at full speed suction pipe friction, feet of water	2.8	2.2
Discharge pipe friction to condenser entrance, feet of water	1.8	1.4
Condenser friction, feet of water	5.1	16.3
Condenser discharge pipe friction, feet of water	1.5	3.6
Difference between suction and discharge water level, feet of water	Negligible	0.3
Total head overcome by pump, feet of water	11.2	23.8
Total water circulated, gallons per minute	45,800	82,400
Efficiency of pumps percentage from	60.5	78.5
Power input to pumps, horsepower	220	634

[1] N.E.L.A., Prime Movers Committee, Report, 1923.

Table XXXIII gives the estimated performance of the two pumps on the same condenser if equipped for variable-speed drive.

TABLE XXXIII.—DUPLICATE PUMPS ON A 50,000-SQ. FT. CONDENSER—VARIABLE SPEED[1]

	One pump	Two pumps
Speed of pumps, per cent of maximum	100	56
Suction pipe friction, feet of water	2.8	0.6
Discharge pipe friction to condenser entrance, feet of water	1.8	0.3
Condenser friction, feet of water	5.1	5.0
Condenser discharge pipe friction, feet of water	1.5	1.5
Difference between suction and discharge water level, feet of water		
Total head overcome by pumps, feet of water	11.2	7.4
Total water circulated, gallons per minute	45,800	45,800
Efficiency of pumps	60.5	78.5
Power input to pumps, horsepower	220.0	112.0

[1] *Ibid.*

The condensers should be installed to get the full siphon effect of the discharge and should have no tubes higher than the center line of the high point of the siphon. The use of bleeding to a

greater extent may not mean less condensing surface, as the turbines may be designed to utilize vacuums with the smaller weight of steam and the vacuum will be largely influenced by the design of the lower turbine stages. Bleeding raises the point at which the limit of economy due to high vacuum is obtainable

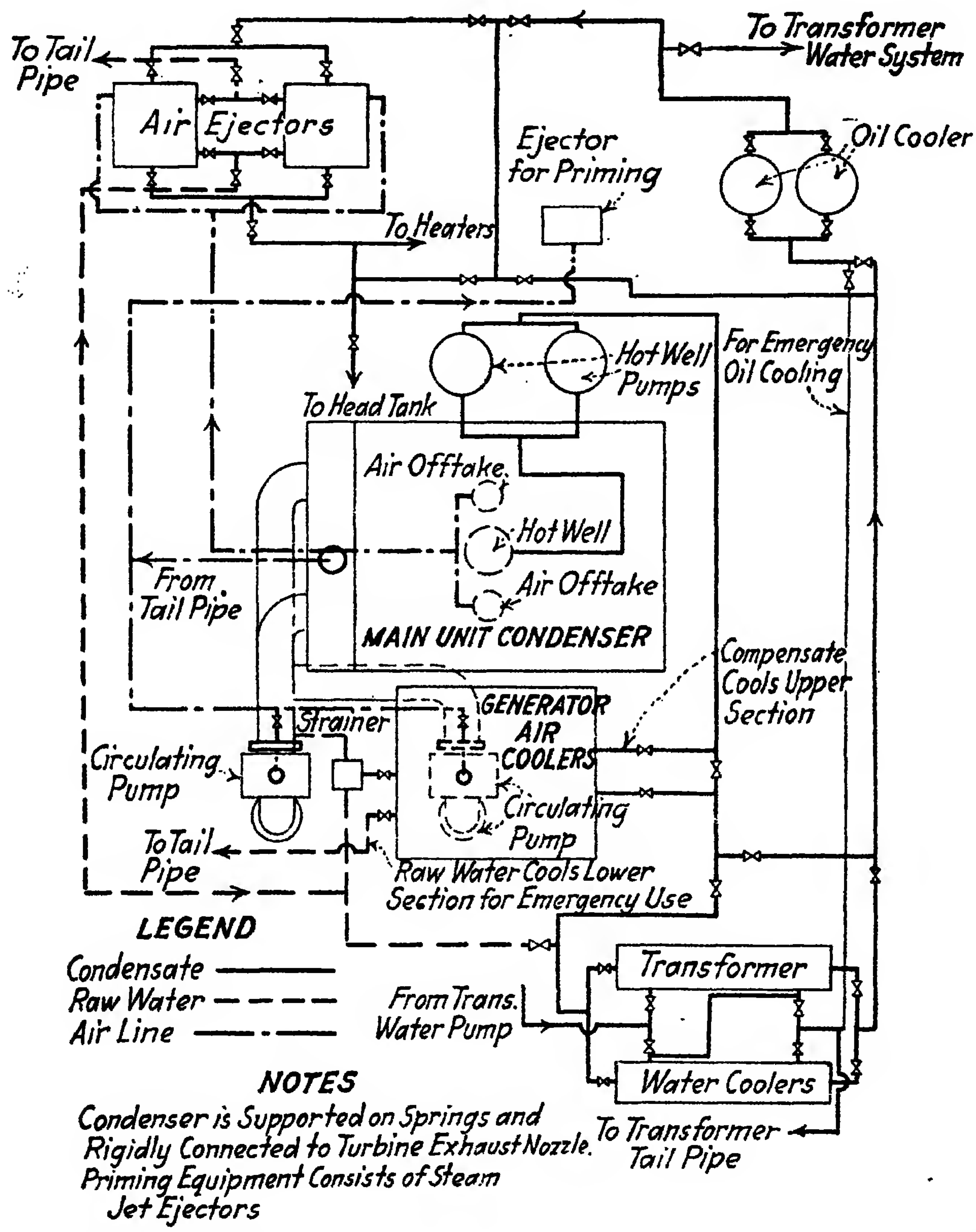

FIG. 128.—Condensing equipment in the Colfax station of the Duquesne Light Company, Pittsburgh. Units 3 and 4.

for a given machine and therefore no great change should be expected in the amount of cooling surface required by condensers.

The most efficient means for varying the quantity of circulating water on either a one- or two-pump installation is by the use of variable-speed driving motors. The efficiency is about the same at all flow rates and reliability of service is gained on

a two-pump installation, since both pumps may run continuously from two independent power sources. Also the total pumping head is reduced on the two-pump installations when both pump suction and discharge pipes are utilized.

The staggering of tubes and the use of partitions seem to be valuable innovations in condenser design and the extent to

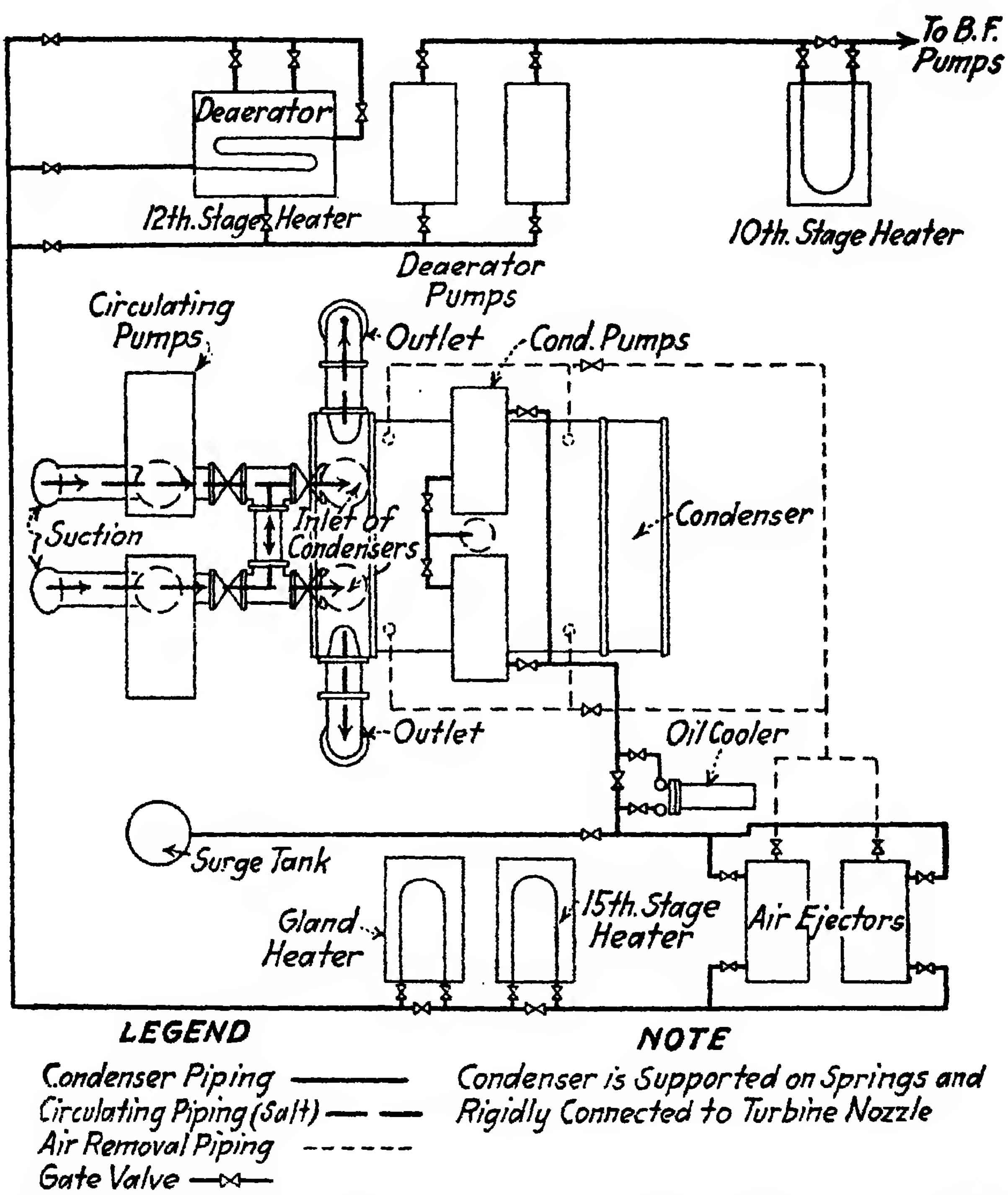

FIG. 129.—Condensing equipment in the Somerset station of the Montaup Electric Company.

which tube size and water velocity are interlinked with power requirements and condenser cleanliness is the subject of a great deal of study. Graduated tube spacing has proved good in single-pass and two-pass types, and this practice is becoming increasingly popular for large installations.

For good operation no condenser tubes should be higher than the center line of the high point of the siphon, and submerged-

tube installations decrease rather than increase operating reliability. Rubber expansion joints between the condenser and the turbine exhaust give very satisfactory results. The effect of bleeding steam from the turbine for feed-water heating may or may not reduce the amount of condenser surface needed. The turbine may be designed to use the higher vacuum, or other local operating conditions will affect the conclusions to be made.

The heat transfer in a condenser is affected by the weight of steam condensed per unit of time, the amount of air leakage, the inlet circulating-water temperature, the cleanliness of tubes, the volume and velocity of the circulating water, the volume of gases removed by pumps and the arrangement of tubes. The most active element in limiting heat transfer is the air carried into the condenser, which although very small in comparison to the volume of steam, is very effective in insulating the tubes. Every precaution should be used to keep air from the condenser and to remove it if leakage occurs. The whole condenser installation is a vitally important unit in the station design and the use of proper condenser auxiliaries is imperative for securing reliable operation and economical fuel consumption.

Condenser tubes are an important element in cost and performance and a tentative specification covering Admiralty tubes and ferrule stock has been prepared by the A.S.T.M. and covers the following requirements:

	Per Cent
Copper	Minimum 70
Tin	Minimum 0.90
Lead	Maximum 0.075
Iron	Maximum 0.06
Zinc	Remainder

Grain Size.—Maximum 0.045 mm. with an average of 0.015 to 0.035 mm. at a magnification of 75 diameters.

Hammer Test.—Specimen from end of tube flattened until gage set at three times metal thickness will page over tube.

Pin Test.—A pin having a taper of 1½ in. per foot driven into tube until diameter is increased 16⅔ per cent.

Mercurous Nitrate Test.—Specified by developing fracture

Hydrostatic Test.—One thousand pounds per square inch.

Dimension Variations.—For the tubes of a specified thickness of 0.035 to 0.049 in., thickness should not exceed that specified by more than 0.005 in. and for tubes of a thickness of 0.065 to 0.083 in., thickness not to exceed that specified by more than 0.007 in.

Weight.—Should not exceed calculated amount by more than 5 per cent.

Length.—Should not be less but may be 1/16 in. more than ordered length at 70°F.

Compression and Hardness Test.—No compression test or hardness test is included in the specification.

The entering end of a condenser tube usually wears out first because of the "piping" effect of the water, which leaves a space for corrosive gases to gather. Reversing of tubes at intervals, the use of a nozzle-shaped liner at the entrance of the tubes or the use of paint on the first part of the tubes are remedies practiced.

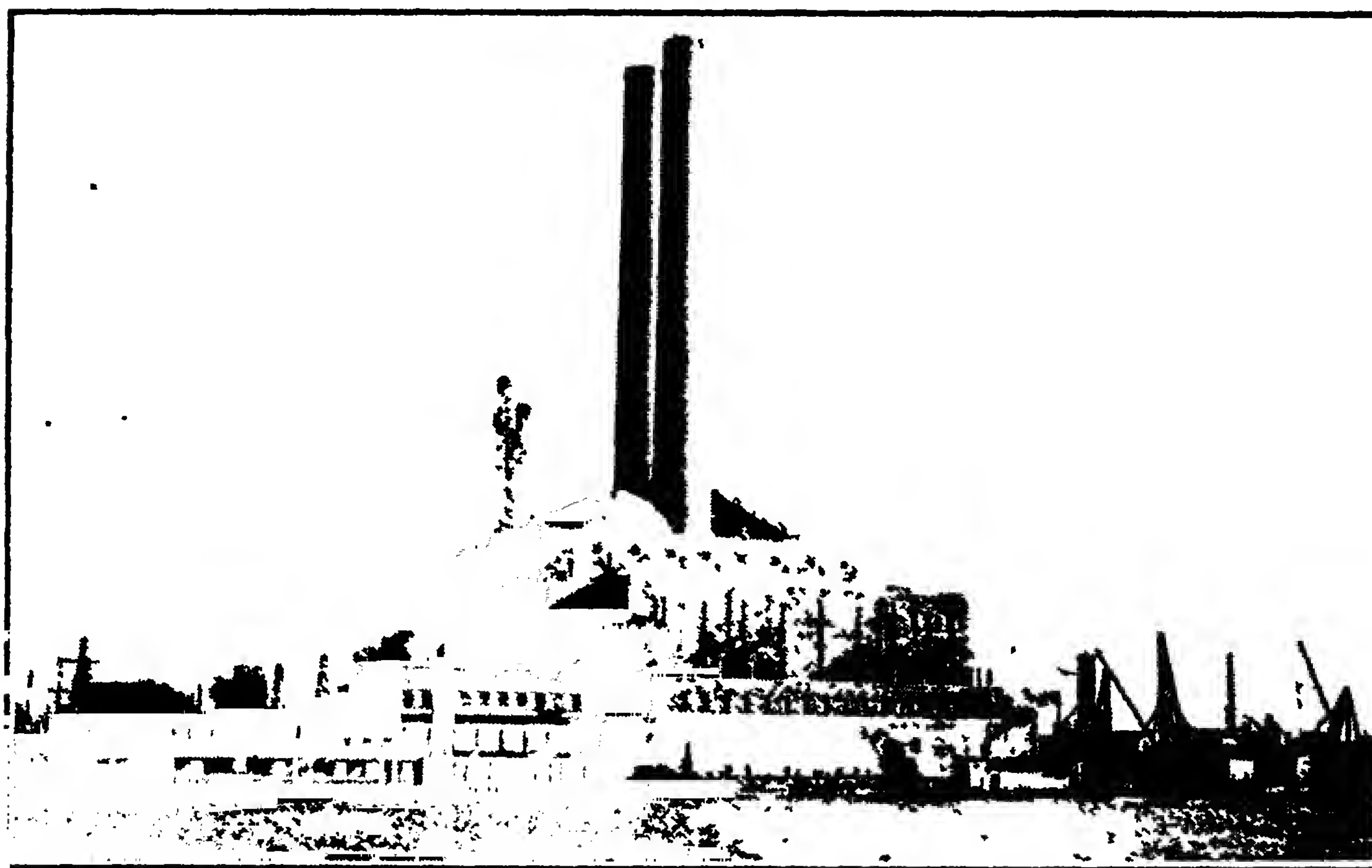

FIG. 130.—View of Cahokia station of the Union Electric Light and Power Company of St. Louis.

A condenser may be either rigidly connected to the turbine casing and supported on springs, or rigidly supported and connected to the turbine casing by a flexible or sliding joint. There are at present three classes of joints: the rubber expansion joint, the sliding joint with mercury seal and the packed sliding joint sealed with water.

Rubber expansion joints installed on circulating pumps are apt to give trouble unless properly supported. If subjected to severe vibration and to varying degrees of vacuum and pressure, as brought about by conditions of low and high tide, there should be a metal reinforcing ring on the inside and one on the outside to prevent breathing and cracking. For the same reason the rubber connection between the condenser and the circulating

TABLE XXXIV.—PERFORMANCE TEST DATA[1]

(60,000 kw. unit auxiliaries test, Hudson Avenue station of Brooklyn Edison Company)

Date	Mar. 26, 1925	Mar. 26, 1925	Mar. 26, 1925	Mar. 26, 1925	Mar. 27, 1925	Mar. 27, 1925
Duration of test, hours	1	1	1	1	1	1
Date of last condenser cleaning	Mar. 15, 295	Mar. 15, 1925	Mar. 15, 1925	Mar. 15, 1925	Mar. 15, 1925	Mar. 15, 1925
Load on unit, net kilowatts	23,940	23,890	36,620	37,200	48,050	48,920
Condensate (not including bleed), pounds per hour	235,130	237,300	354,500	356,000	507,460	503,230
Vacuum at turbine exhaust (referred to 30-in. bar.), inches, Hg	29.01	29.09	28.91	28.99	28.23	28.31
Vacuum at hot well (referred to 30-in. bar.), inches Hg	28.96	29.01	29.44	29.45	28.34	28.46
Vacuum at air offtake (referred to 30-in. bar.), inches Hg	29.18	29.21	29.16	29.16	28.39	28.51
Coefficient of heat transmission, B.t.u. per square foot per degree Fahrenheit	112	111	158	150	150	148
Circulating pumps:						
Circulating water inlet, degrees Fahrenheit	42.5	42.4	42.9	42.7	42.7	43.0
Circulating water, end first pass, degrees Fahrenheit	45.3	44.3	46.3	44.8	47.0	45.3
Circulating water outlet, degrees Fahrenheit	48.8	46.2	51.3	48.4	55.4	51.4
Circulating water both pumps, grams per minute	71,000	115,000	78,000	116,000	74,600	115,000
Condenser friction head, feet of water	5.1	14.9	5.4	15.2	5.5	14.8
External friction head, feet of water	2.0	5.0	2.0	5.0	2.0	5.0
Power input to two circulating pumps, kilowatts	219.2	671	216.1	665	214.7	658
Hot-well pumps:						
Power input to one hot-well pump, kilowatts	42.3	42.5	46.1	46.1	51.8	51.7
Hot-well temperature, degrees Fahrenheit	69.3	67.9	72.5	71.5	91.0	88.5
Air-removal apparatus:						
Hurling water for h.v. air pump, degrees Fahrenheit	42.5	42.4	42.9	42.7	42.7	43.0
Air leakage, cubic feet free air per minute	22	22	22	22	22	22
Power input to air pump, kilowatts	57.4	57.4	57.4	57.4	57.4	57.4
Steam to steam jets, pounds per hour	1,500	1,500	1,500	1,500	1,500	1,500

Note: Figures on air-removal apparatus are guarantee figures.

[1] N.E.L.A., Prime Movers Committee, *Report*, 1926.

water discharge pipe should be supported and braced on the inside to prevent collapsing. Also the rubber connection between the condenser and the free exhaust should be reinfored in order to prevent failure.

Air removal from the condenser is accomplished by means of a rotary dry vacuum pump, a steam ejector, a hydraulic vacuum pump or combinations of these devices.

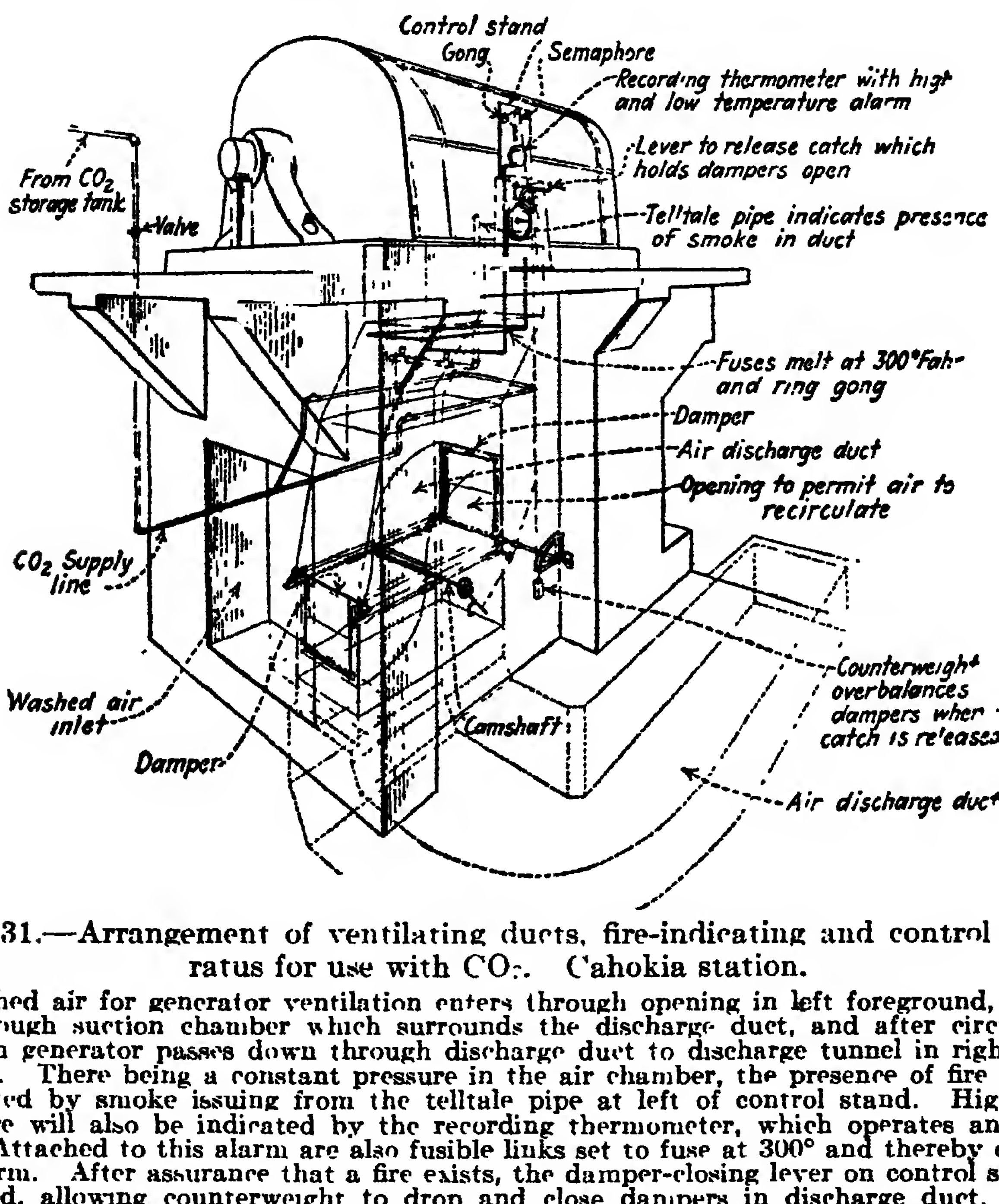

FIG. 131.—Arrangement of ventilating ducts, fire-indicating and control apparatus for use with CO_2. Cahokia station.

Washed air for generator ventilation enters through opening in left foreground, passes up through suction chamber which surrounds the discharge duct, and after circulating through generator passes down through discharge duct to discharge tunnel in right foreground. There being a constant pressure in the air chamber, the presence of fire will be evidenced by smoke issuing from the telltale pipe at left of control stand. High temperature will also be indicated by the recording thermometer, which operates an alarm bell. Attached to this alarm are also fusible links set to fuse at 300° and thereby operate the alarm. After assurance that a fire exists, the damper-closing lever on control stand is operated, allowing counterweight to drop and close dampers in discharge duct. Their position is indicated by a semaphore. The operation of the dampers also uncovers an opening between discharge duct and suction duct, permitting recirculation of cooling air. Immediately upon closure of dampers, the cam shaft operates to wedge the doors against supporting angles and thereby prevent air leakage. CO_2 gas is then admitted to the closed ventilating circuit to stifle combustion, by operating valve in CO_2 supply line.

Which of the methods mentioned is the most economical depends on several factors, such as the first cost, maintenance cost and the amount of power required to operate them, but the steam-jet ejector is most commonly used.

To give an idea of the equipment needed for a condenser installation, its performance and a form of specification and bid

TABLE XXXV.—SCHEDULE OF CONDENSER BIDS, MORRELL STREET PLANT, PUBLIC LIGHTING COMMISSION, CITY OF DETROIT

I. Bidder		Allis-Chalmers Co.		Elliott Co.		Elliott Co.		Ingersoll-Rand	
II. Address		Milwaukee, Wis.		Pittsburgh, Pa.		Pittsburgh, Pa.		New York	
III. Price, 3 units		$214,900		$187,583		$184,583		$176,500	
IV. Price, 4 units		283,200		250,000		246,000		235,333	
			Per cent tolerance		Per cent tolerance		Per cent tolerance		Per cent tolerance
1. Delivery time, weeks		50	−5	35, 44, 48, 52	+5	35, 44, 48, 52	+5	52	4 weeks
2. Erection time, weeks		20	−5	9 weeks after last delivery	+5	9 weeks after last delivery	+5	32	4 weeks
3. Net weight without tubes, pounds		196,000	±5	222,000	±5	222,000	±5	140,000	5
4. Net weight circulating pump, pounds		13,000	±5	12,000	±5	12,000	±5	21,000	5
5. Net weight condensing pump, pounds		3,000	±5	1,000	±5	1,000	±5	1,350	5
6. Tube surface, square feet		32,000	0	32,000	0	32,000	......	16,000	0.5
7. Circulating water, gallons per minute	1 pump	26,500	+5	20,000	±3	20,000	±3	25,000	3
	2 pumps	40,000	+5	40,000	±3	40,000	±3	40,000	3
8. Absolute back pressure, inches, of Hg., two pumps, circulating water at 55°F. steam condensed.	Lb. per Hr.								
	250,000	1.15	0	1.05	0.4	1.05	0.4	1.2	3 % of load
	210,000	1.0	0	0.9	0.4	0.9	0.4	1.0	3 % of load
	160,000	0.85	0	....	....	....	....	0.85	3 % of load
	120,000	0.8	0	....	....	....	....	0.8	3 % of load
9. Absolute back pressure, inches, of Hg., one pump, circulating water at 55°F.	Lb. per Hr.								
	210,000	1.2	0	1.25[a]	0.4	1.25[a]	0.4	1.3	3 % of load
	160,000	1.0	0	1.0[a]	0.4	1.0[a]	0.4	1.05	3 % of load
	120,000	0.85	0	....	....	....	....	0.9	3 % of load
10. Loss of head through condenser, feet	1 pump	8	±10	5	5	5	5	3.4	7
	2 pumps	15	±10	14	5	14	5	8.5	7

11. Circulating pump characteristics, two pumps operating.	Horsepower	158	+5	118	±5	118	±5	103.5	3
	Speed, r.p.m.	350	0	390	±3	390	±3	246	
	Head, ft.	25	0	18	±5	18	±5	16	
	Efficiency, per cent	80	0	77	−0+3	77	−0+3	78	
12. Condensate pump characteristics..	Horsepower	57	+5	46	±5	46	±5	55	3
	Speed, r.p.m.	1,150	0	1,800	±3	1,800	±3	170	
	Head, ft.	180	0	150 external	±5	150 external	±5	150 disch.	
	Efficiency, per cent	50	0	60	−0+3	50	−0+3	52	
13. Steam required, pounds per hour, each, air removal equipment.	1st stage	600	±3	650	±5	650[b]	±5	240	3
	2nd stage	700	±3	190	±5	190[b]	±5	600	
14. Characteristics, hydraulic and R.D.V. pumps.	Horsepower								
	Speed, r.p.m.								
	Horsepower	....	....	......	......	......	......	10	3
	Speed, r.p.m.	....	....	......	......	......	......	275	
15. Temperature differences, degrees Fahrenheit, steam entering condensate and condensate leaving hot well. Circulating water, 55°F.	Lb. per Hr.								
	210,000	8	±10	2	0	2	......	2.5	
	160,000	10	±10	2	0	2	......	2.5	
	120,000	12	±10	2	0	2	......	3	
16. Pressure drop, inches of Hg., exhaust steam inlet to air offtake condensate, 210,000 lb. per hour, back pressure, 1 in. absolute..........		0.2	0	0.1	0	0.1	......	0.1	
Number of tubes..........		6,115	....	6,150	......	6,150	......	3,500, ⅞ in. dia.	

[a] Taken from curve. [b] Common inter- and aftercooler for both equipments.

TABLE XXXV.—SCHEDULE OF CONDENSER BIDS, MORRELL STREET PLANT, PUBLIC LIGHTING COMMISSION, CITY OF DETROIT.—(Continued)

I. Bidder		Westinghouse Electric Co		C. H. Wheeler Mfg. Co.		Wheeler Cond. & Eng. Co.		Worthington Pump Co.	
II. Address		East Pittsburgh, Pa.		Philadelphia, Pa.		Carteret, N. J.		Harrison, N. J.	
III. Price, 3 units		$283,800		$206,550		$241,800		$235,500	
IV. Price, 4 units		378,400		275,400		320,000		314,000	
			Per cent tolerance		Per cent tolerance		Per cent tolerance		Per cent tolerance
1. Delivery time, weeks		3 units 50 4 units - 52		20, 24, 28, 32	2 weeks	20 to 32	0	First 6 months 3 weeks intervals	
2. Erection time, weeks		3 units 36 4 units 38		6 weeks per unit	10 days transit	10	0	45 days per unit after arrival	
3. Net weight without tubes, pounds		148,000		174,000	7	169,000	5	178,000	5
4. Net weight circulating pump, pounds		11,125		16,500	7	17,500	5	14,750	5
5. Net weight condensing pump, pounds		2,250		2,000	7	1,500	5	3,000	5
6. Tube surface, square feet		32,000		32,000	1	32,000	0	32,000	
7. Circulating water, gallons per minute	1 pump	26,000		25,000	5	32,000	0	28,000	
	2 pumps	40,000		40,000	5	40,000	0	40,000	
8. Absolute back pressure, inches of Hg., two pumps, circulating water at 55°F., steam condensed.	Lb. per Hr			Not to exceed	Expected				
	250,000	1 14		1.05	0.95 in.	1.02	0	1.01	
	210,000	0 99		0.95	0.85	1.0	0	1.0	
	160,000	0 8		0.8	0 7	1.0	0	1.0	
	120,000	0.8		0.7	0.6	1 0	0	1.0	
9. Absolute back pressure, inches of Hg., one pump circulating water at 55°F.	Lb per Hr.								
	210,000	1 18		1.15	1.05	1.0	0	1.01	
	160,000	0 97		0 95	0.85	1.0	0	1.0	
	120.000	0.8		0.8	0 7	1.0	0	1.0	

10. Loss of head through condenser, feet..	1 pump	9	......	8	....	7	5	6.25
	2 pumps	13	......	14	....	11	5	12.25
11. Circulating pump characteristics, two pumps operating.	Horsepower	167	......	130	....	132	2	126
	Speed, r.p.m.	490	......	300	....	290	2	360
	Head, ft.	25	......	20	....	20	2	20
	Efficiency, per cent	75.5	......	78	1	76	0	80
12. Condensate pump characteristics.	Horsepower	92	......	51.5	....	56	2	50
	Speed, r.p.m.	1,750	......	1,750	....	1,750	2	1,200
	Head, ft.	185	......	180	....	185	2	183
	Efficiency, per cent	31	......	53	2	50	0	55
13. Steam required, pounds per hour, each, air removal equipment.	1st stage	380	......	300	5	390	2	210[b]
	2nd stage	1,030	......	625	5	390	2	490[b]
14. Characteristics hydraulic and R.D.V. pumps.	Horsepower	64	......	......	....	......	..	52.5
	Speed, r.p.m.	700	......	......	....	......	..	1,800
	Horsepower	......	......	......	....	......	..	20
	Speed, r.p.m.	......	......	......	....	......	..	120
15. Temperature differences, degrees Fahrenheit, steam entering condensate and condensate leaving hot well. Circulating water, 55°F.	Lb. per Hr.			Not to exceed	Expected			
	210,000	2.0	......	at 1 in. vac. 5	4	2	0	3
	160,000	2.4	......	at 1.5 in. vac. 4	3	3	0	4
	120,000	2.8	......	at 2 in. vac. 3	2	5	0	
16. Pressure drop, inches of Hg., exhaust steam inlet to air offtake condensate, 210,000 lb. per hour, back pressure, 1 in. absolute		0.15	......	Not given	....	0.05	0	0.2
Number of tubes		6,088	......	6,112	....	......	..	6,820 18 ft. 3 in.

[b] Common inter- and aftercooler for both equipments.

used on power house bids for the city of Detroit, the following material from *Power*[1] is recorded:

Extent of Work.—The following work is not to be included as a part of that covered by these specifications:

1. Foundations and supporting steel work.
2. All motors without pulleys or couplings delivered to contractor f.o.b. cars Detroit or at his receiving point, as he may designate.
3. All piping except that hereinafter specified.
4. All starters, controllers and electric wiring connections.
5. Atmosphere relief valves.
6. Main condenser tubes and ferrules delivered f.o.b. cars at plant.

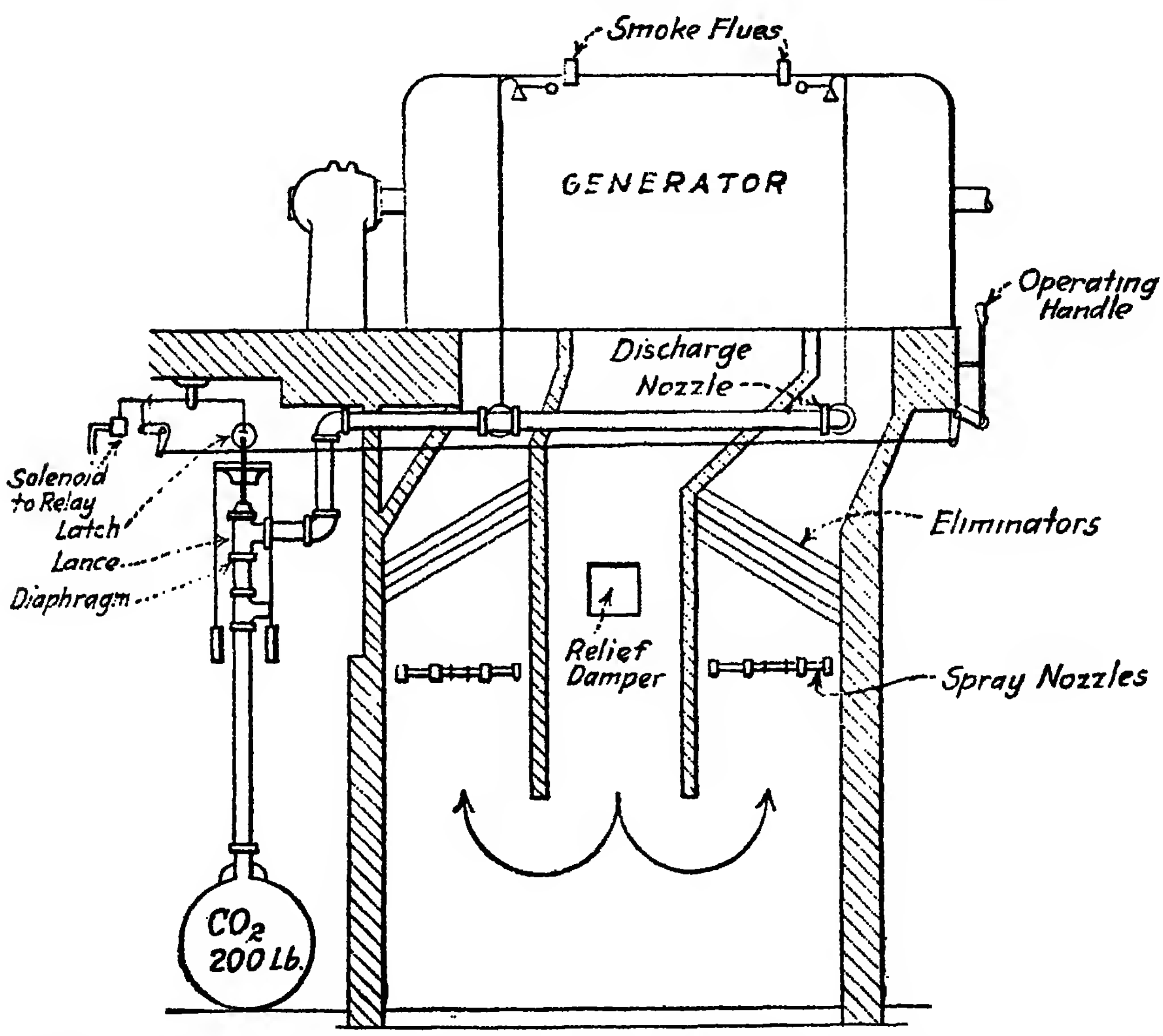

FIG. 132.—A CO_2 installation at the South Meadow station of the Hartford Electric Light Company.

CO_2 is admitted to the generator when the relay-actuated lance pierces the diaphragm in the CO_2 line.

All other work, including all labor, materials, equipment and accessories further mentioned or necessary for constructing the condenser units hereinafter specified, shall be done as a part of the work covered by these specifications.

Number Required.—Three or four units shall be furnished at the option of the commission.

Description of Unit.—Each unit shall consist of a surface condenser, circulating pumps, condensate pumps, air-removal equipment, interconnecting piping and connection to turbine exhaust.

[1] Vol. 58, No. 24.

Capacity.—Each unit shall be capable of reducing the absolute back pressure at the turbine exhaust to 1 in. Hg when the turbine is exhausting 210,000 lb. of steam per hour and the temperature of the circulating water is 55°F.

Condenser.—The condenser shall be two-pass, containing not less than 32,000 sq. ft. of cooling surface. It shall be rigidly attached by means of a distance piece to the turbine exhaust and supported on springs.

The cooling surface shall consist of 1-in. outside diameter tubes of such copper alloy as the commission may decide to purchase. Tube plates shall be Muntz metal at least 1⅜ in. thick and of such diameter that the tubes do not occupy more than 33 per cent of the area circumscribed by the inner edge of the water boxes. Both tube sheets of each condenser shall be drilled and tapped for packing and ferrules.

Circulating Pumps.—Two centrifugal double-section volute-type circulating pumps, each mounted on a common subbase with and direct connected to a variable-speed electric motor, shall be furnished with each condenser. The two pumps shall be capable of simultaneously discharging through their condenser 20,000 U. S. gal. per minute each when the water level in the intake conduit is 2 ft. lower than that in the discharge conduit.

The impellers shall be of government bronze with all surfaces machined or hand filed. Impeller inlets shall be provided with renewable bronze labyrinth rings. Shafts shall be protected from the water by removable bronze sleeves. Bearings shall be ring oiling, horizontally split, renewable and independent of stuffing boxes.

Condensate Pumps.—Two centrifugal volute-type condensate pumps mounted on a common subbase with and direct connected to a constant-speed electric motor shall be furnished with each condenser. Each pump shall be capable of discharging not less than 600 gal. per minute against a head of 150 ft. not including the vacuum on the pump section.

The character of construction shall be equal to that specified for circulating pumps.

Air-removal Equipment.—Air-removal equipment shall be of the steam-jet type. There shall be two equipments complete with inter- and after-condenser for each condenser unit. Each equipment shall be capable of withdrawing 19 cu. ft. of free dry air at 70°F. and 28½-in. vacuum and 13 cu. ft. at 29-in. vacuum referred to a 30-in. barometer.

Steam for jets will vary from 300 to 325 lb. per square inch gage with 200° of superheat. Any pressure regulator required to reduce this pressure to a point suitable for the jets shall be provided, one for each equipment. Alternate proposals on air-removal equipment of the hydraulic and rotative dry vacuum type will be considered at the option of the bidders.

Piping.—The following piping connections shall be furnished and installed with each condenser:

1. Suction lines with bell-shaped inlets from intake conduit to circulating pumps.

2. Discharge connections with hydraulically operated gate valves from circulating pumps to condenser.

3. Overflow pipe with bell-shaped outlet from condenser to discharge conduit.

TABLE XXXVIa.—DETAILS OF AIR-

Number	In parallel with	Name of plant	Make of air-extraction apparatus	Number of off takes	Number of steam-jet sets	Number of stages	Number of nozzles per stages, Stages 1	2	3	Steam pressure at nozzles, lb. gage	Source of steam for nozzles
1	.	Colfax	Westinghouse	2	2	2	2	2		210	Main steam
3	H.V.	Valmont	Westinghouse	2	1	2	1	1		175	Aux. steam
4	.	Springdale. .	Westinghouse	2	4	2	1	1		225	Aux. steam
5		Waterside 1	Wheeler C. & E. Co.	2	2	2	2	2		130	Aux. steam
6		Waterside 1	Ingersoll-Rand	2	2	2	3	2		135	Aux. steam
7	. .	Lakeside	Wheeler C. & E. Co.	2	2	2	3	3		125	Aux. steam
8	.	Somerset	Wheeler C. & E Co.	6	2	2	1	1	. .	135	Aux. steam
9	.	Wabash River	Westinghouse	2	1	2	2	2	. .	175	Aux. steam
12	.	Northeast	Wheeler C. & E. Co.	2	2	2	3	3	. .	150	Main steam
14	. .	Hell Gate	Westinghouse	2	2	2	2	2	.	150	Aux. steam
15	. .	Hell Gate . .	Westinghouse	2	1	2	3	3		150	Aux. steam
16	.	Midway	Wheeler C. & E. Co.	2	1	3	2	2	2	. .	Boiler
17	.	Midway. .	Croll-Reynolds	2	1	2	2	2		250	Boiler
18		Longbeach.	Westinghouse	2	2	2	2	2		175	Aux. steam header
23	H.V.	Hudson Ave	Westinghouse	2	1	2	12	12		150	Live steam
24											
27		Lincoln	Westinghouse	2	2	2	1	1		175	Aux. steam line
33	.	Hales Bar	Radojet	4	2	2	1	1		125	Main steam
34	.	Hales Bar	Alberger	6	2	2	1	1		140	Main steam
35	.	Crawford Ave.	Weir	12	6	3	1	5	12	190	Aux steam
36	H.V.	Crawford Ave.	Worthington	2	2	2	1	1		130	Aux steam
37	H.V.	Crawford Ave.	Westinghouse	12	1	2	1	1		180	Aux. steam
39	R D.V.	Montville .	Wheeler C. & E. Co.	2	1	2	9	19		135	Aux. steam
40		East Peoria. .	Alberger	2	2	2	1	1		140	Main steam
44		Omaha. .	Wheeler C. & E. Co.	4	2	2	1	1		135	Main steam
45	.	Saxton .	C. H. Wheeler	4	2	2	17	1	.	250	Aux. steam

EXTRACTION APPARATUS—STEAM JETS

Type of intercooler	Type of aftercondenser	Source cooling water	Remarks	Priming equipment
Surface	Surface	Total condensate from hot well	32 c.f.m. at 70°F. & 15 in. Hg	Steam-jet air ejectors
Surface	Surface	Total condensate from hot well	51 c.f.m. at 70°F. & 2 in. Hg	Condenser air-extraction sets
Surface	Surface	Total condensate from hot well	38 c.f.m. at 1 in. Hg	Steam-jet air ejectors
Surface	Surface	Total condensate from hot well	24 c.f.m. at 1 in. Hg	Steam-jet air ejectors
Surface	None	Circulating water	....	Steam-jet air ejectors
Surface	Surface	Intercooler 12.5 per cent of condensate. Aftercondenser 87.5 per cent of condensate	60 c.f.m. at 1 in. Hg	Steam-jet air ejectors
Surface	Surface	Total condensate from hot well	38 c.f.m. 3 air offtakes	"Hytor" vacuum pump
Surface	Surface	Total condensate from hot well	35 c.f.m. at 70°F.	Central priming system
Surface	Surface	Total condensate from hot well	....	Steam
Surface	Surface	Half of intercooler uses raw water. 125 g.p.m. Other half and aftercondenser uses total condensate	34 c.f.m. at 70°F. & 1 in. Hg	Steam-jet air ejectors
Surface	Surface	Intercooler uses raw water. 200 g.p.m. After condenser uses total condensate	56.5 c.f.m. at 70°F. & 1 in. Hg	Steam-jet air ejectors
Surface	Surface	Intercooler uses raw water. 200 g.p.m. After condenser uses total condensate		
None	None			
Surface	Surface	Total condensate from hot well	....	"Hytor" vacuum pump
Surface	Surface	Total condensate from hot well	54 c.f.m. at 70°F. & 2 in. Hg	Steam-jet air ejectors
Jet	None	Condensate 55 g.p.m.	24 c.f.m.	Steam-jet air ejectors
Surface	Surface	Total condensate from hot well	53 c.f.m. at 1 in. Hg. Two air offtakes on each side	Steam-jet air ejectors
Surface	Surface	Intercooler—river water. Aftercondenser—total condensate	22 c.f.m. at 1 in. Hg. 3 air offtakes on each side	Steam-jet air ejectors
Surface	Surface	First intercooler—river water. Second intercooler—total condensate. Aftercondenser—total condensate	6 air offtakes per shell	Steam-jet air ejectors
Surface	Surface	Condensate from hot well	20 c.f.m. at 1 in. Hg. 1 air offtake per shell	Steam-jet air ejectors
Surface	Surface	Condensate from hot well	18.3 c.f.m. at 1 in. Hg. 6 air offtakes per shell	Steam-jet air ejectors
Surface	Surface	Condensate from hot well	25 c.f.m. at 1 in. Hg. Air offtakes on side of shell	Steam-jet air ejectors
Surface	Surface	Condensate from hot well		
Surface	Surface	Condensate from hot well	72 c.f.m. at 70°F. & 2 in. Hg. air offtake on side of condenser	Steam-jet air ejectors
Surface	Surface	Condensate from hot well	22 c.f.m. Two air offtakes on each side	Retrex vacuum pump

TABLE XXXVI*b*.—DETAILS OF AIR-EXTRACTION

Number	In parallel with	Name of plant	Make of air-extraction apparatus	Number of air offtakes	Number of H.V. sets	Number of hurling water pumps	Number of nozzles	Hurling water, gallons per minute	Source of hurling water
3	S J	Valmont	Westinghouse	2	1	1	3	800	Tank
10		Northeast	Worthington	1	1	2	3	3,200	City water
11		Northeast	Worthington	2	1	2	4	2 000	City water
13		Hell Gate	Worthington	2	1	2	4	2 000	Tank
19		South St	Westinghouse	2	2	2	2	3,000	Main injection pipe
20		Delaware	Westinghouse	2	2	2	2	2,000	Disch. of circ. pumps
23	S J	Hudson Ave	Westinghouse	2	1	1	1	1 665	Disch of circ. pumps
24									
25		Devon	Westinghouse	2	2	2	2	1,000	In-take tunnel
30		High Bridge	Worthington	1	1	1	3	1,600	Air wash pump line
31		Amsterdam	Worthington	1	..	2	2	1 000	Tank water
32		West End	Worthington	1	1	2	4	3,200	.
36	S J.	Crawford Ave	Worthington	2	1	2	4	2 000	Disch of circ. pumps
37	S.J		Westinghouse	12	2	1	1		Disch. of circ pumps
38		"L" Street Unit "9 & 10".	Worthington	3		2	3	1 800	Water from harbor
38		Unit "II"	Worthington	4		2	4	1 800	Water from harbor

APPARATUS—HYDRAULIC VACUUM PUMPS

Speed of hurling pump, revolutions per minute	Power for each pump, horse power	Type of driving mechanism	Remarks	Priming equipment
690	50	Electric motor	17.5 c.f.m. at 70° water & 2 in. Hg	Inverted loop connected to either the H.V. or S.J. condenser air extraction sets
1,800	165	Electric motor	15 c.f.m. per nozzle	Steam-jet air ejectors
1,800	75	Electric motor	11 c.f.m. per nozzle	Steam-jet air ejectors
1,200	75	Electric motor	4.7 c.f.m. per nozzle at 5 in. Hg	Connection to condenser air extraction set
500	202	Direct connected to circulating pump	Air offtake on level with cone (jet condensers)	Motor driven centrifugal pump
720	100	A.c. motor	25.92 c.f.m.	Steam-jet air ejectors
	95	Steam turbine		
690	85	A.c. motor	22 c.f.m. at 70°F. & 2 in. Hg	Steam-jet air ejectors
700	50	Electric motor	10 c.f.m.	Steam-jet air ejectors
1,150	75	Electric motor	Air offtake on side of shell. 10.26 c.f.m. at 40°F. water and 75 in. Hg	Steam siphon and condenser air-extraction set
1,200	75	Electric motor	Air offtake on side of Shell. 13 c.f.m.	Steam-jet air ejectors
1,800	153	Induction motor	Air offtake on side of shell. 44 c.f.m.	Steam-jet air ejectors
1,160	100	Electric motor	One air offtake in each shell. 20 c.f.m. & 2 in. Hg	Steam-jet air ejectors
700	64	Electric motor	Six air offtakes in each shell 18.3 c.f.m.	Steam-jet air ejectors
1,740	170	1 motor 1 turbine		
1,740	170	1 motor 1 turbine		

TABLE XXXVIc.—CHARACTERISTICS OF CONDENSER INSTALLATIONS RECENTLY PUT INTO SERVICE

No.	Name of company	Name of station	Source of circulating water supply	Capacity of station	Number of unit	Rating of unit	Condenser surface	Quantity of circulating water	Temperature of circulating water, Temperature, degrees Fahrenheit		
				Kw.		Kw.	Sq. ft.	G.p.m.	Avg.	Min.	Max.
1	Duquesne Light Co.	Colfax, Cheswick, Pa.	Allegheny River	180,000	3 A	30,000	55,000	70,000	55	32	79
2	Detroit Edison Co.	Trenton, Chan. Mich.	Detroit River	150,000	1	50,000	47,300	100,000	50	32	80
3	Public Service Co., Denver, Col.	Valmont, Boulder, Col.	Artificial Lake	20,000	1	20,000	30,000	36,000	..	39	75
4	West Penn. Power Springdale, Pa.	Springdale, Pa.	Allegheny River	120,000	3 & 4	36,000	55,000	70,000	53	33	80
5	New York Edison Co.	Waterside, N. Y. C.	East River (Sea water)	....	10	35,000	30,000	60,000	55	36	74
6	New York Edison Co.	Waterside, N. Y. C.	East River (Sea water)	....	12	35,000	30,000	70,000	55	36	74
7	Milwaukee El. Ry. & Lt. Co.	Lakeside, Milwaukee	Lake Mich.	130,000	5	30,000	50,000	50,000	45	35	70
8	Montaup El. Co., Fall River, Mass.	Somerset, Somerset, Mass.	Tauton River	30,000	1	30,000	45,000	60,000	60	35	75
9	Indiana El. Corp.	Wabash River, Terre Haute, Ind.	Wabash River	40,000	..	20,000	40,000	40,000	..	33	80
10	Kansas City Power & Light Co.	Northeast Kansas, City Mo.	Missouri River	120,000	2 & 3	20,000	35,000	35,000	55	33	89
11	Kansas City Power & Light Co.	Northeast Kansas, City Mo.	Missouri River	120,000	4	30,000	38,260	45,000	55	33	89
12	Kansas City Power & Light Co.	Northeast Kansas, City Mo.	Missouri River	120,000	5	30,000	45,000	45,000	55	33	89
13	United El. Lt. & Po. Co.	Hell Gate, N. Y. C.	East River (Sea water)	285,000	5	35,000	50,000	70,000	55	32	74
14	United El. Lt. & Po. Co.	Hell Gate, N. Y. C.	East River (Sea water)	285,000	6	50,000	63,000	90,000	55	32	74
15	United El. Lt. & Po. Co.	Hell Gate, N. Y. C.	East River (Sea water)	285,000	7	50,000	65,000	76,000	55	32	74
16	San Joaquin Lt. & Pr. Co., Fresno, Cal.	Midway Button-Willow, Cal.	Cooling Ponds	20,000	1	10,000	30,000	24,000	85	75	105

17	San Joaquin Lt. & Pr. Co., Fresno, Cal.	Midway Button-Willow, Cal.	Cooling ponds	20,000	2	10,000	30,000	24,000	85	75	105
18	Southern Cal. Edison Co., Los Angeles Cal.	Long Beach, Cal.	Pacific Ocean	70,000	8	35,000	35,000	70,000	62		
19	Narraganset El. Lt. Co.	South St., Prov. R. I.	Providence River	125,000	7 4	45,000	Jet 2 cond.	36,000	55	32	90
20	Philadelphia El. Co.	Delaware, Phila., Pa.		180,000		30,000	50,000	42,500	58	33	80
21	San Diego Cons. Gas & El. Co.	Station "B," San Diego, Cal.	San Diego Bay	21,000	21	15,000	28,000	30,000	65	58	75

TABLE XXXVIc.—CHARACTERISTICS OF CONDENSER INSTALLATIONS RECENTLY PUT INTO SERVICE.—(*Continued*)

No.	*Make of condenser*	Number of water passes	Position of condenser	Type of condenser support	Connection between turbine exhaust and condenser	Diameter of condenser tubes	Number of tubes	Length of condenser tubes	Material of tubes	Type of ferrules and tube packing	Type of water box
						Inches		Feet			
1	Westinghouse	Two	Horizontal	Springs	Solid	1	10,500	20.25	Admiralty	Fiber packing	Divided
2	Worthington	Single	Horizontal	Springs & hydraulic jacks	Solid	1	7,640	24.0	Admiralty	Allen packing	Single
3	Westinghouse	Two	Horizontal	Springs	Solid	1	6,085	18.8	Muntz	Crane metallic packing	Single
4	Westinghouse	Two	Horizontal	Springs	Solid	1	10,500	20.0	Admiralty	Tubes rolled at one end, fiber packing at other end	Divided
5	Wheeler Cond. & Eng. Co.	Single	Horizontal	Springs & hydraulic jacks	Solid	7/8	5,694	23.0	Admiralty	Paraffined corset lacing	Divided
6	Ingersoll Rand	Single	Horizontal	Springs & hydraulic jacks	Solid	7/8	5,950	22.0	Admiralty	Venturi ferrules at outlet, paraffined corset lacing	Divided
7	Wheeler Cond. & Eng. Co.	Three	Horizontal	Springs	Solid	1	9,450	20.0	Muntz	Corset lacing	Single
8	Wheeler Cond. & Eng. Co.	Two	Horizontal	Springs	Solid	1	9,080	19.25	Admiralty	Venturi ferrules corset lacing	Divided
9	Westinghouse	Two	Horizontal	Springs	Solid	1	7.640	20.0	Muntz	Fiber packing	Divided
10	Worthington	Two	Vertical	Solid	Water seal sup. type exp. joint	1	7,425	18.0	Muntz	Duck and fiber	Single
11	Worthington	Two	Vertical	Solid	Water seal sup. type exp. joint	1	8,119	18.0	Muntz	Duck and fiber	Single
12	Wheller Cond. & Eng. Co.		Vertical	Solid	Water seal sup. type exp. joint	1	9,550	18.00	Muntz	Venturi ferrules fiber & corset lacing	Single
13	Worthington	Two	Horizontal	Springs & hydraulic jacks	Solid	1	9,990	19.25	Admiralty	Paraffined corset lacing	Divided
14	Westinghouse	Two	Horizontal	Springs & hydraulic jacks	Solid	1	12,688	19.0	Admiralty	Paraffined corset lacing	Divided

15	Westinghouse	Two	Horizontal	Springs & hydraulic jacks	Solid	⅞	14,934	19.0	Admiralty	Expanded at inlet to each pass, paraffined corset lacing	Divided
16	Wheeler Cond. & Eng. Co.	Two	Horizontal	Solid	Exp. joint	1	5,725	20.4	Admiralty	Crane metallic packing	Single
17	Allis Chalmers	Two	Horizontal	Solid	Exp. joint	1	6,200	19.25	Muntz	Crane metallic packing	Single
18	Westinghouse	Two	Horizontal	Springs & hydraulic jacks	Solid	1	10,504	20.0	Admiralty	"Dura" metallic packing	Divided
19	Westinghouse	....	....	Solid	Exp. joint	....	....	....	....	....	....
20	Westinghouse	Two	Horizontal	Springs	Solid	1	9,094	21.25	Admiralty	Square-faced ferrules, molded metallic rings for packing	Single
21	Worthington	Two	Horizontal	Springs	Solid	1	5,348	20.2	Admiralty	Crane metallic packing	Single

TABLE XXXVIc.—CHARACTERISTICS OF CONDENSER INSTALLATIONS RECENTLY PUT INTO SERVICES.—(*Continued*)

No.	Circulating pumps: Number per condenser	Circulating pumps: (Maximum) capacity of each pump, G.p.m.	Circulating pumps: Rotative speed, R.p.m.	Circulating pumps: Power of driving mechanism per pump, H.p.	Circulating pumps: Type of driving mechanism	Type of hot well	Maximum condensate	Condensate pumps: Number per condenser	Condensate pumps: Number of stages	Condensate pumps: Capacity of each pump, G.p.m.	Condensate pumps: Rotative speed, R.p.m.	Condensate pumps: Power of driving mechanism per pump, H.p.	Condensate pumps: Type of driving mechanism	Type of air-extraction equipment	No.
1	2	35,000	290	450	Induction motor	Plain	307,500	2	2 stage	1,000	1,130	125	Wound rotor induction motor	S.J.	1
2	2	50,000	175–255	325	D.c. motor	Deaërating	423,000	2	6 stage combined b.f. and cond. pump	1,300	1,000–1,200	700	1 d.c. motor & 1 steam turbine	R.D.V.	2
3	2	22,000	490	175	1 motor 1 Duplex (Motor and turbine)	Deaërating	184,500	2	Single	600	1,750	40	1 motor 1 steam turbine	H.V. & S.J.	3
4	2	35,000	248–292	300	Wound rotor induction	Deaërating	370,000	2	2 stage	790	1,150	100	Squirrel cage induction motor	S.J.	4
5	2	30,000	290	200	Steam turbine	Plain	414,000	2	2 stage	1,000	1,450	44	Steam turbine	S.J.	5
6	2	35,000	400	290	Steam turbine	Plain	417,500	2	Single stage	1,260	1,450	65	Steam turbine	S.J.	6
7	2	25,000	360	250	Constant speed a.c. motor	Plain	300,600	1	2 stage	800	1,200	60	Constant speed a.c.	S.J.	7
8	2	40,000	190–290	250	Variable speed motor	Plain	314,000	2	2 stage	660	1,200	50	Constant speed motor	S.J.	8
9	2	25,000	385–500	150	Slip ring motor	Plain	204,000	2	2 stage	630	1,150	75	Constant speed motor	S.J.	9
10	1 vertical	35,000	498	460	Electric motor	Plain	210,000	2	2 stage	800	1,200	. . .	Motor	H.V.	10
11	2	30,000	1–300 & 400 1–400	200	1–2 speed motor 1 motor	Plain	312,000	2	2 stage	825	1,200	100	Motor	H.V.	11
12	2	20,000	290	175	Motor	Plain	312,000	2	3 stage combined b.f. and cond. pump	825	1,200	. . .	Motor	S.J.	12

13	2	35,000	196 & 360	400	2 speed squirrel cage induction motor	Deaërating	375,000	2	2 stage	1,350	1,200	75	Squirrel cage induction motor	H.V.	13
14	2	45,000	193–345	400	2 speed squirrel cage induction motor	Plain	575,000	2	2 stage	1,500	870	75	Squirrel cage induction motor	S.J.	14
15	2	38,000	193–290	240	2 speed squirrel cage induction motor	Plain	575,000	2	2 stage	1,500	870	75	Squirrel cage induction motor	S.J.	15
16	1	24,000	350	500	Steam turbine	Plain	125,000	2		500	1,800	25	1 steam turbine 1 motor	S.J.	16
17	1	24,000	550	475	Steam turbine	Plain	133,000	2		500	1,750	25	1 steam turbine 1 a.c. motor	S.J.	17
18	2	35,000	216–290	250	Variable speed slip ring induction motor	Plain	307,500	2	2 stage	1,000	960	75	Constant speed a.c. motor	S.J.	18
19	2	18,000	500	500	Steam turbine		534,000							H.V.	19
20	2	45,000	500	450	1 Induction motor duplex synchronous motor & turbine	Plain	333,000	2	Single	1,200	1,800	125	1 induction motor 1 steam turbine	H.V.	20
21	1	30,000	435	250	Duplex motor & turbine	Plain	183,750	2	2 stage	500	1,250	23	Steam turbine	R.D.V.	21

NOTES.—All installations covered in this table use cast-iron condenser shells and Muntz metal tube sheets.
All installations covered in this table use centrifugal circulating and condensate pumps.

[a] S.J. = Steam jet air pump.
H.V. = Hydraulic vacuum pump.
R.D.V. = Reciprocating dry vacuum pump.

4. Suction connections with gate valves from condenser hot wells to condensate pumps.

5. Air connections with valves from condenser to each air-removal equipment.

Turbine Exhaust Connections.—Each condenser shall be provided with a cast-iron filler piece complete with bolts and gaskets and connected to turbine exhaust.

Accessories.—Each condenser unit shall be provided with gage, thermometers, mercury column, hinged doors to permit cleaning, hot-well gage glasses, supporting springs and hydraulic jacks, and all bolts and connections necessary for anchoring and attaching the equipment to the foundations and supporting steel work.

One set of wrenches and such special tools as are required by peculiarities of design shall be provided.

Shop Tests.—Such one of the circulating pumps as the engineer may designate shall be tested in the shops for performance. If this pump fails to meet the guarantees, such of the remaining pumps shall be tested as the engineer may require.

The condensate pumps shall be similarly tested.

Delivery and Erection.—The equipment comprising each condenser unit with all auxiliaries and accessories shall be delivered and completely erected

Recent condenser installations and some details of the steam-jet and hydraulic vacuum-pump installations as given by the N.E.L.A. Prime Movers Committee, 1926, are shown in Table XXXVI.

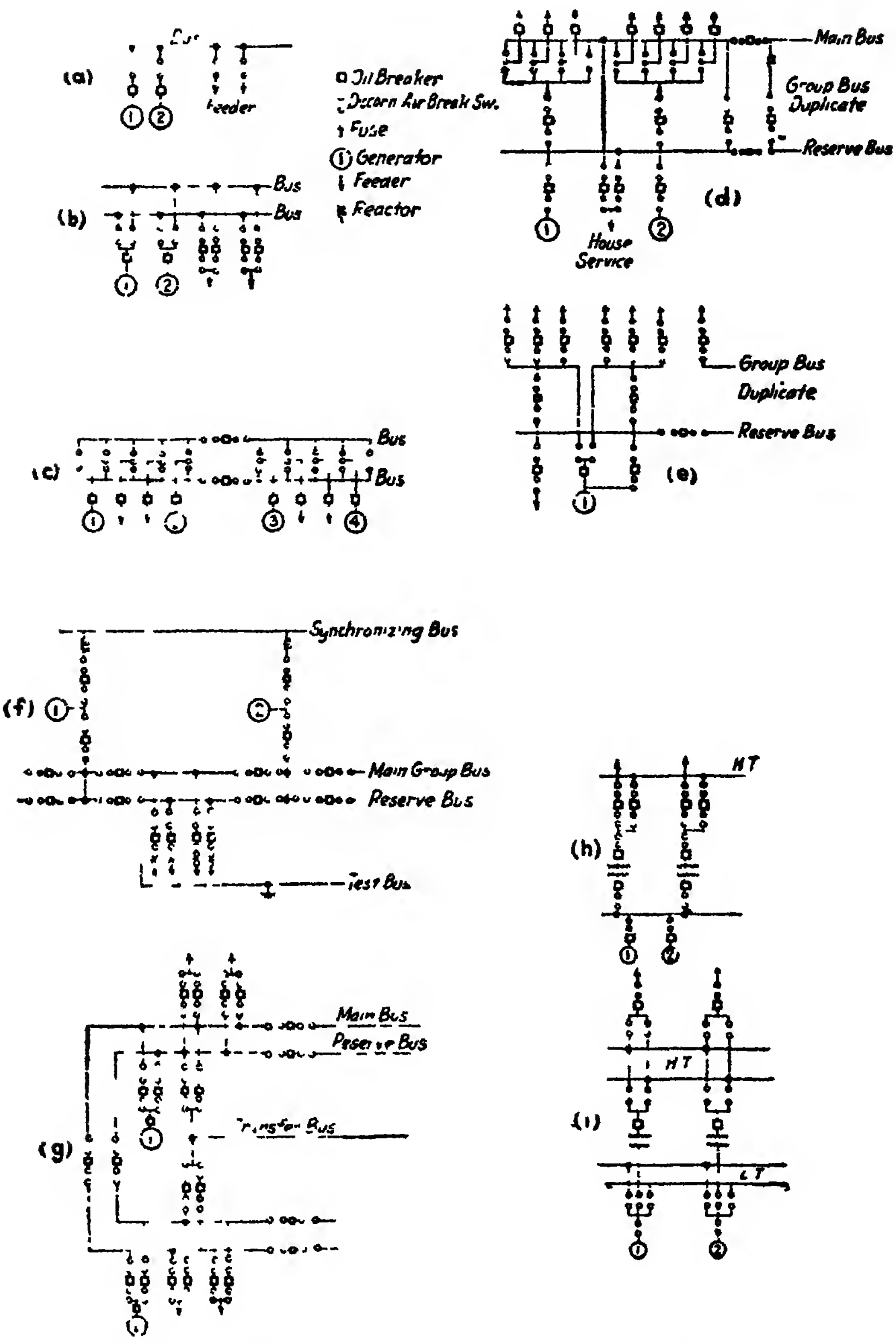

FIG. 134a.—Typical electrical layouts for power stations.

a Single-line layout Used on small stations only. It is simple and cheap but inflexible and permits a minimum of service reliability.

b Double bus with double or single oil breakers. One bus may be used for lighting and the other for power When used with single breakers and double disconnects it is used in small plants but is inflexible and does not permit of remote control. Even with double breakers the arrangement is advisable for small stations only.

c. Ring bus layout This is a very common arrangement for stations, as it permits group feeding and gives economy in copper. Disadvantage lies in its inflexibility should breaker troubles occur.

d. Main and group feeder bus layout. Used in large stations where great service flexibility is desired.

e Unit group feeder layout. Used in large stations operating on a unit basis. Great flexibility is obtained and the system is well adapted to remote control.

f. Group feeder layout. A very flexible and effective arrangement where the breakers are interlocked.

g. Double ring and transfer bus layout. A complicated and expensive layout which gives great flexibility and provides for continuous service.

h. Unit system with high-tension transfer bus. Normal operation requires low-tension switching.

i. Unit system with no low-tension breakers. Not adopted to remote control very readily.

the use of large amounts of copper, strong and massive construction, heavy-current-capacity equipment and very complete control and protection features to insure reliable service. Care must be taken to limit currents to faults, to secure flexibility in switching and to protect against abnormal voltages.

The second class of station introduces the problem of insulation and in addition affords opportunity for decision as to the amount of high-tension equipment it is advisable or economical to install

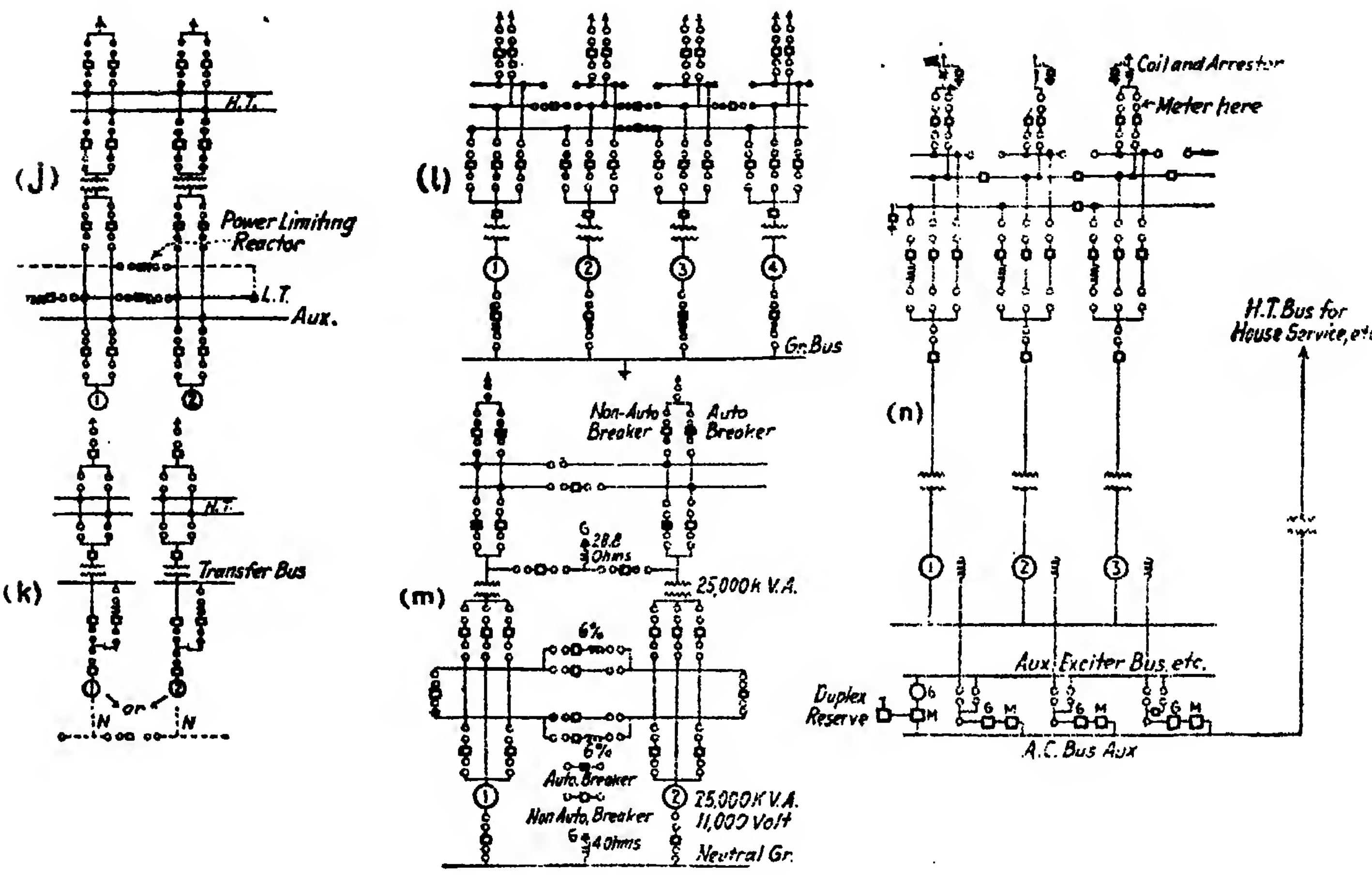

FIG. 134*b*.—Typical electrical layouts for power stations.

j. Double-bus, double-breaker system. Good but very expensive.
k. Double high-tension bus with a transfer or ground bus. Adapted to unit-system operation where all energy is transmitted at high voltage.
l. High-tension sectionalization with low-tension ground bus. Used on large systems to give unit operations.
m. Unit double bus with ground bus. A flexible arrangement with reactor protection and unit operation.
n. Unit system with group feeders. Used on large plants to secure unit operation and flexibility.

in buildings. And the third class introduces all the elements of design and operation found in the other two classes.

But in addition to these classifications, stations may be designed to operate as base load plants, that is, continuously at rated load, or they may carry a fluctuating load and either of these operating conditions may be associated with conditions brought about by interconnection with other stations of the same or different characteristics. And base-load plants of today may become standby or peak-load stations of tomorrow because of changes introduced in a short period of time. Thus it is difficult,

indeed, to plan the electrical features for a station under existing conditions and have it satisfy conditions even 5 years hence.

Abnormal troubles in the electrical portion of a station arise from switching, short circuits and grounds, and 95 per cent of these troubles are introduced by faults occurring on the lines or feeders supplied from the station. It is a rather simple procedure to disconnect a faulty feeder or line causing trouble or to protect individual pieces of apparatus in the station if continuity of service is not considered. Unfortunately, however, service is a paramount consideration even to the extent of perhaps damaging equipment, and the problem is therefore complicated by this condition. The result is an attempt to isolate the troubled section and to supply its load from other sections without interrupting service. The equipment required to limit and isolate troubles consists in reactors, oil breakers, automatic air-disconnect switches and relays of various types with adequate control wiring. And the addition of this protective equipment adds to service hazards and design complication because it makes another link which must operate 100 per cent of the time to be efficient in its duty and means must be provided for inspecting and repairing this equipment without interrupting service.

Thus in laying out a station it is imperative to keep the proper perspective as regards the relative importance and reliability of each item required in the assembly both for the given station and in conjunction with its operation with other plants or parts of the system. Some typical low-tension station layouts, high-tension layouts and combination station layouts are shown in Figs. 134*a* and 134*b*, inclusive. The high-tension station equipment may or may not be inside the switch house and the general trend is to place it in an outdoor station near the switch house. Also the switch house and buses may or may not be separated from the turbine room by a fire wall or even be housed in a separate building, depending on the size of the station and operating conditions. In some cases vertical- or horizontal-phase isolation will be used for the station design.

Bus and Switch Structures.—The fundamental considerations for designing the bus and switch structures are safety and reliability, convenience in operation and fire protection. Every precaution must be taken to safeguard the plant operation in the event of abnormal disturbances and at the same time the layout must be simple and economical. The use of steel trucks, cubicles,

structural compartments or pits and other barriers is warranted on circuits of less than 25,000 volts in order to localize trouble, but where high voltages are used space is a great factor, so that, depending on capacity and voltage, the compartment method is not used. The use of outdoor structures also eliminates the use of compartments and the tendency is to go to such structures on the large high-voltage plants.

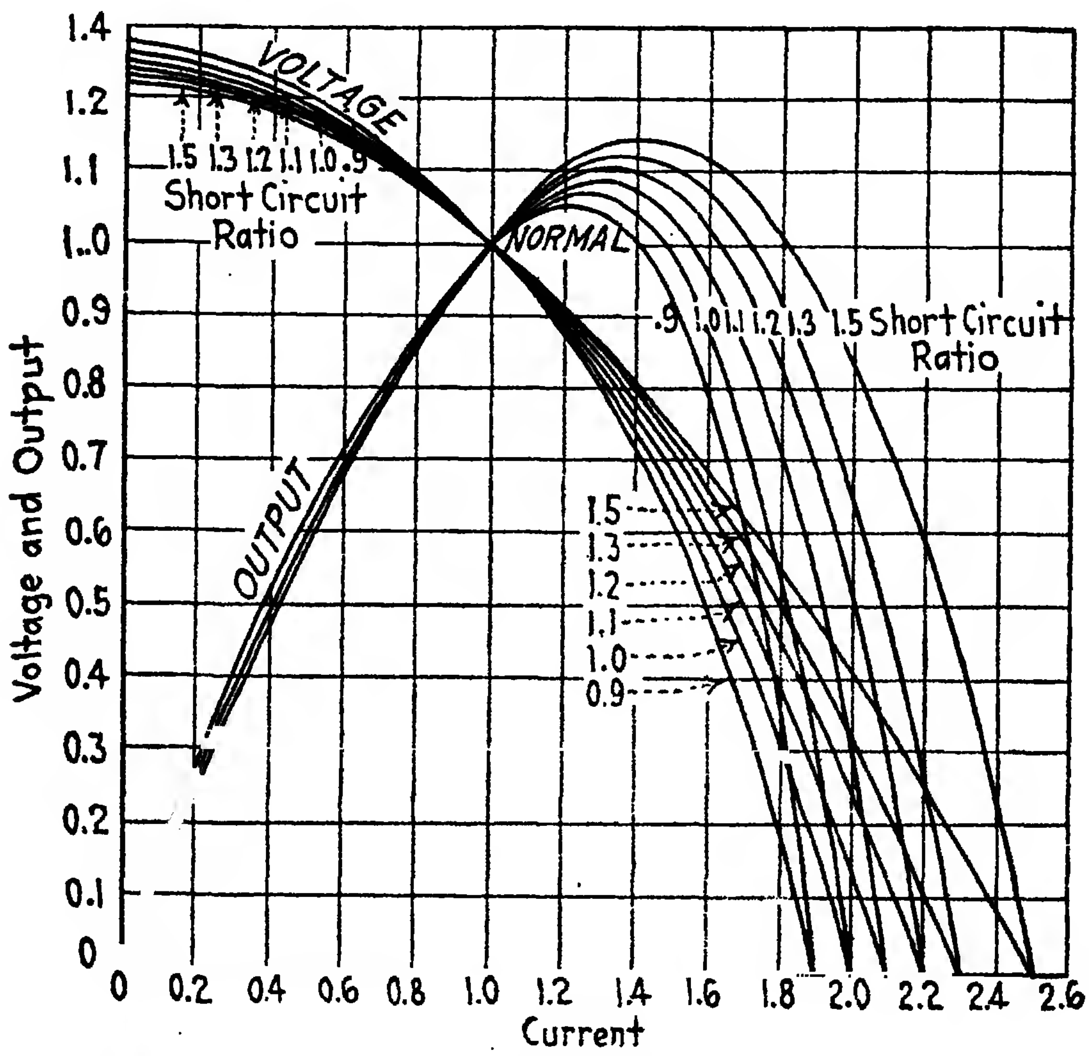

FIG. 135.—External characteristic curves of a salient-pole 80 per cent power factor 60-cycle alternator based on an average machine reactance of 20 per cent. (*W. J. Foster, General Electric Review, June*, 1923.)

The compartment may be used for bus, oil breaker, instrument transformer, etc. and its function is largely to prevent trouble from spreading to adjacent apparatus. The compartments are usually built of steel, brick, concrete or a combination, although soapstone and slate and asbestos board have also been used. The brick compartment is best for all-around purposes, as the concrete requires reinforcing in most bus structures and a fault is communicated to adjacent apparatus very readily through the reinforcing material. Concrete slabs without reinforcing, however, make admirable barriers to separate compartments made of brick, and they are cheaper to install. All compartments should have removable doors which swing from the top, are made from

fireproof material and have vent holes. Asbestos board is very commonly used. Each compartment door should be protected by signal, card, electrical or mechanical lock or a switch so that the door cannot be opened when the inside structure is alive. One of the most convenient methods is a push-button switch and signal lamps just over the compartment door. A late development is the all-steel compartment with dead-front safety-truck type switchboard, and this offers many advantages over older methods, especially in the lower voltages.

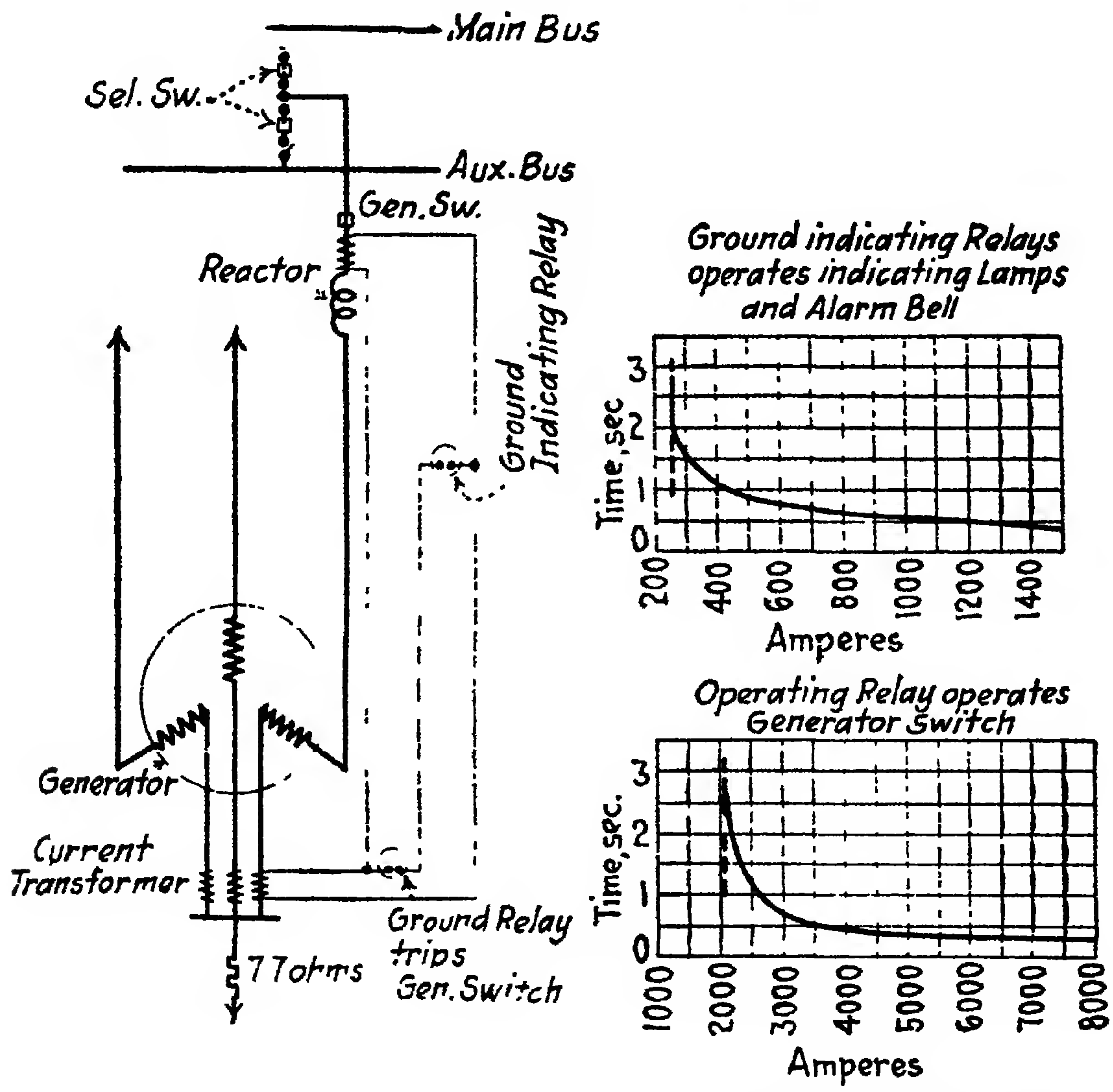

FIG. 136.—Characteristics and connections for differential and ground relays on a 13,200-volt, sixty-cycle generator in the Hell Gate station of the United Electric Light and Power Company, New York.

In laying out a switch house, space must be left for instrument transformers and disconnect switches. These are usually placed in separate compartments and in some cases bushing-type current transformers can be used to advantage. In locating oil breakers and transformers extreme care must be exercised so as to place them in a position where a short circuit or the rupture of a tank will not produce a fire or cause burning oil to spread over the plant. Pits are sometimes used and in other cases oil-tight compartments are used. Simplicity and convenience as well as

costs enter into the location of such apparatus and usually a compromise is made.

The low-tension bus bars should be made of built-up laminations to reduce skin effect and should be placed on edge to give better ventilation. An important point in laying out the bus-bar supports is to allow for mechanical stresses in the event of a short circuit and to allow for the expansion and contraction of the bus copper with changes in the temperature of the bus copper. With 77°F. as normal, a rise in temperature to 110° will cause the bus copper to expand about 0.35 in. per 100 ft., while a drop to 25° will cause the copper to contract about 0.6 in. or a total change of about 0.95 in. per 100 ft. may readily occur in bus copper. The bus clamps should be in compression and not in tension and proper adjustments for removing or changing a defective clamp or insulator must be made. There are many special devices on the market which serve for specific cases. Another important factor in the layout is to get sufficient strength in the supports for the disconnect switches, since the mechanical force used to open or close the switch will be optional with the individual operator.

The control wiring for switchboard apparatus and meters is a constant source of trouble in that it requires frequent inspection and change for calibrating and test purposes. In the event of trouble the whole station may be closed, so that every effort should be made to get this type of wiring located in a safe and convenient space. The bottom of a control panel board or the back of a switchboard is a poor place to work and it pays to have special panels or a room located beneath the switchboard proper to which all control wires are led through conduit to fused test panels. These panels allow tests, changes and calibrations to be made very readily and conveniently and at the same time safeguard the station service.

In planning a plant layout it is also necessary to arrange for lighting under any conditions, even if this involves the installation of a battery. The installation and the location of a testing set for testing out all circuits at the will of the operator are features often overlooked. This test set and its control and wiring will usually be found most convenient on the floor that contains the house-service switchboard and switchboard-control wiring panels, but very often the specific location will be determined by the plant considered. Every effort should also be

made to secure ample space and convenience for the house-service switchboard and wiring, since the plant functions adequately only so long as this service is maintained. Also the economic operation of the plant depends very largely on the reliability and ease with which adjustments can be made on the house-service apparatus.

Alternators.—The electrical energy stream in a central station starts at the alternator, which acts as the agency for transforming the mechanical energy of the steam turbine or water wheel into electrical energy. And the electrical energy, although in itself

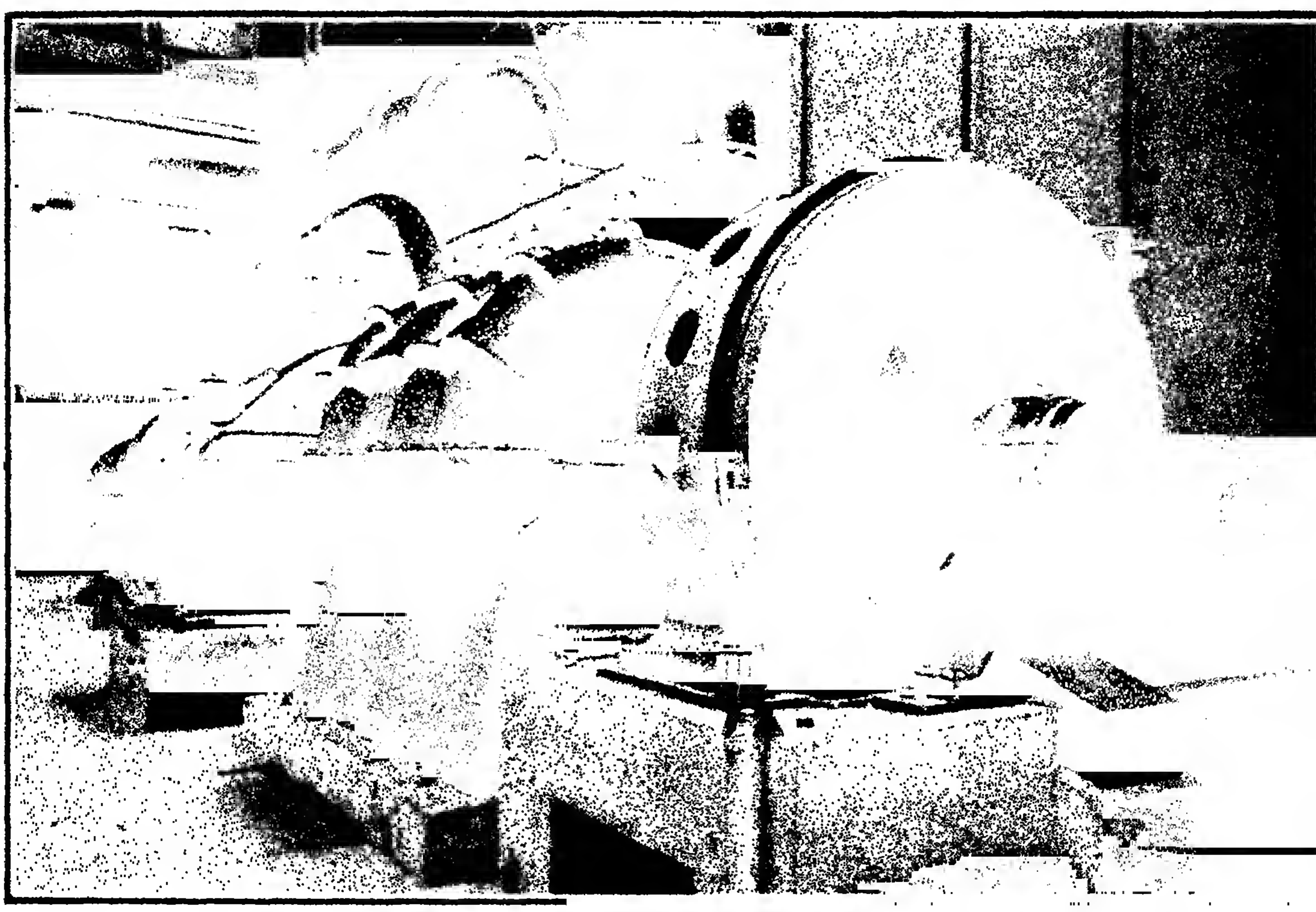

Fig. 137.—Dual drive, consisting of a steam turbine and synchronous motor, on a circulating water pump in Delaware station of the Philadelphia Electric Company.

intangible, behaves according to well-defined quantitative laws, so that rigid design and performance calculation can be made.

The physical structure of the alternator consists of a rotating portion called the rotor, which carries the excitation winding, and a stationary structure called the stator, which carries the windings which supply the outgoing energy circuits. The rotor is built of high-grade steel or nickle-steel alloy either as a solid forging or as a built-up structure of discs and has slots radially located for holding the field winding. The stator is a cast frame holding built-up laminations which contain ventilating ducts and the slots for holding the stator winding.

A wide range of speeds and ratings are commercially available, the largest being rated 62,500 kva. The maximum peripheral speed for rotors in American practice is abour 450 ft. per second for maximum output conditions, and because of this limitation and others the rotor of a four-pole, 75,000-kw. unit weighs no less than 100 tons and has an active core 20 ft. long and 54 in. in diameter.

The vibrational, centrifugal and electro-magnetic forces in an alternator are very large, and special wedges, end braces, steel rings, etc. are used to hold the windings in place against electro-

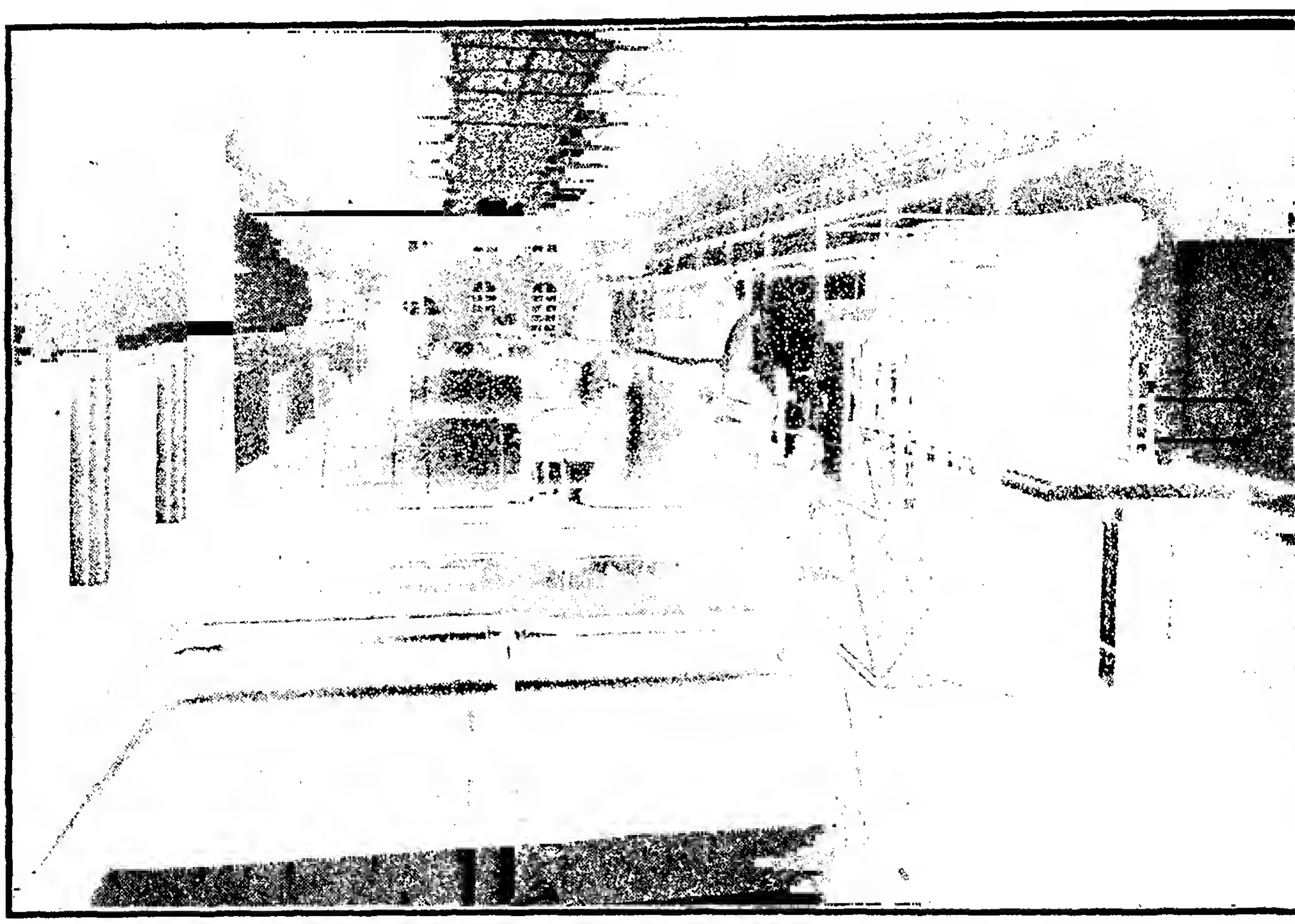

FIG. 138.—Interior of turbine room in the Waterside station of the Louisville Gas and Electric Company.

magnetic forces and forces produced by the effect of heat. The expansion coefficients of copper, steel and insulation differ widely and give resultant stresses of great magnitude. For example, the insulation of the end turns may be subjected to a stress of 4,000 lb. per square inch due to electro-magnetic forces alone in large units.

The limiting factors in alternator capacity are mechanical strength, heating and voltage and all three of these items are interrelated. A commercial alternator is rated in kilovolt-amperes and thus requires a power-factor specification if overload capacity of the turbo-generator unit is to be stated. About 1,600

amp. per square inch of copper with a consequent heat loss of 0.6 watt per square inch represents common design practice with an insulation thickness of about 0.25 in. and iron worked at a density of 60,000 to 100,000 lines per square inch.

Quantitative Relations.—The fundamental formulas applicable to a three-phase alternator are:

$$E = \sqrt{2}\pi N\phi f 10^{-8} \text{ volts},$$

$$I = \frac{e}{\sqrt{(R + r)^2 + (X + x)^2}}.$$

$$E = IZ = e - Iz = \frac{e\sqrt{R^2 + X^2}}{\sqrt{(R + r)^2 + (X + x)^2}}.$$

where e = the e.m.f. generated per phase at no load.
N = the number of stator conductors in series per phase.
f = the frequency in cycles per second.
ϕ = the flux per pole in the air gap at no load.
x = synchronous reactance per phase.
r = effective resistance per phase.
z = synchronous impedance per phase.
Z = load impedance per phase = $R + jX$.
I = current per phase.
E = terminal voltage per phase.

From these equations it is seen that the terminal voltage of an alternator depends on both internal and external constants. The automatic voltage regulator, however, can be used to secure any desired terminal voltage conditions under changing loads, so that alternator designers have leeway in regard to voltage regulation. The ratio of rotor ampere-turns to stator ampere-turns is not so important, and in many machines is about 2 to 1, giving a voltage regulation varying between 25 per cent at unity power factor to 40 per cent at 80 per cent power factor. When used on high-tension lines with heavy-changing currents, special precautions must be taken to secure control over alternator excitation.

The output and power factor of a three-phase alternator under balanced conditions is found from the equation:

$$\text{watts} = \sqrt{3}EI \cos \theta,$$

where $\cos \theta$ is the power factor and E and I are the average values of line voltage and current respectively.

High-voltage alternators have stator windings that are operated in Y-connection, as this permits the neutral to be grounded, gives better facilities for controlling the operation of

the machine and protecting it against grounds and short circuits, gives a higher line voltage for a given phase voltage, gives a greater ratio of copper to insulation in the slots and gives less insulation strain in the ratio of 1 to $\sqrt{3}$ for the same terminal voltage if a delta winding is used.

The wave shape of an alternator should closely approximate a sine wave to prevent harmonics in the voltage or current, depending on the winding, which give trouble on the system or to communication systems. The A.I.E.E. specification as to wave form limits the deviation factor or maximum distance between corresponding ordinates on the vertical scale between the equivalent sine wave and the machine wave to 10 per cent when the waves are superimposed in such a way as to make this difference a minimum.

In order to secure comparable conditions between alternators of different makers and in order to write proper specifications, it is essential that certain features should be specified and standardized. The A.I.E.E. has standardized alternators, in general, as regards operating temperature, mechanical strength, dielectric strength, insulation resistance, efficiency, power factor, wave shape, voltage regulation and rating.

The capacity of an alternator is the load it will carry continuously without exceeding any of the foregoing limitations. The rating of an alternator is simply the manufacturer's nameplate data and is largely based on temperature limitations. The rating is specified in kilovolt-amperes at the terminals of the machine at a specified voltage, frequency and sometimes the power factor for normal kilowatt operation is mentioned.

The limitation in capacity as regards temperature is fixed by the temperature under which the insulation will stand up continuously, as there is no economic advantage obtained from operating at a low temperature. The temperature is usually based on a so-called ambient temperature, which is determined by the temperature of the intake air. The standard A.I.E.E. ambient temperature is 40°C. The limiting temperature as fixed by the A.I.E.E. with built-up mica and asbestos insulation is recommended as 125°C. or a rise of 85° over the standard ambient temperature. A correction is made for altitude when the altitude is in excess of 3,300 ft.

In forced-draft cooling a conventional weighted mean temperature is used as the ambient temperature. A weight of 4 is given

the temperature of the intake air and of 1 to the air in the room. For example, if the air from outside a building is 15°C. and the room temperature is 30°, the ambient temperature from which the temperature rise is computed is

$$T = \frac{4 \times 15° + 1 \times 30°}{5} = 18°\text{C.}$$

If the maximum temperature of the machine is 75°C. under these conditions, then the rise is 75° − 18° = 57°. No acceptance tests should be made with an ambient temperature less than 15°C.

To measure the temperature three methods are available:

1. Thermometers.
2. Thermo-couples.
3. Resistance changes in conductors.

Method 2 is preferable, although it is advisable to use the other methods as a check. The thermo-couples should be about 20 in. long and have a resistance of about 10 ohms at 25°C. They are embedded in the slots in two positions in a two-layer winding and in one position in a single-layer winding.

Several of these couples are built into the machine and can be used under operating conditions to detect the internal temperature. The highest reading of any couple +5°C. determines the so-called hot-spot temperature for a double-layer winding, according to the A.I.E.E. rules. In a single-layer winding the hot-spot temperature equals the maximum thermo-couple temperature +10° +1° per 1,000 volts above 5,000.

Care in writing temperature specifications is warranted. For example, if a machine is rated on a circulating air temperature of 15°C., then the machine has excess capacity in the winter when the peak load occurs. If 105° is the maximum temperature, using the summer intake air at 40° and the winter at 15°C., the available rise is found as

$$\text{Summer} = (105 - 5 - 40) = 60°.$$
$$\text{Winter} = (105 - 5 - 15) = 85°.$$

If a constant volume of air is supplied to the machine, 10 per cent more kilovolt-amperes can be obtained in the winter than in the summer without exceeding temperature limitations, *i.e.*, a 100,000-kva. plant of, say, five 20,000-kva. units in the winter is equivalent to five 20,000-kva. and one 10,000-kva. unit, or 110,000 kva. The hot-spot temperature fixes the rating, however, so care must be used in trying to operate on an average temperature basis.

The temperature limitations for stator and rotor should be the same in order to utilize all the capacity of an alternator in cold weather. The A.I.E.E. rules specify that a turbo-generator shall stand an overspeed of 20 per cent and shall have sufficient mechanical strength to withstand centrifugal forces at this speed and also, for an instant, the forces due to a short circuit.

TABLE XXXVII.—RELATIVE CHANGES IN ALTERNATORS WITH INCREASED RATING

Rating in kilovolt-amperes	Cost per kilovolt-ampere	Efficiency, per cent	Friction, etc.	Rotor Cu	Core	Stator Cu
1,000	$25.00	95	0.9	1.0	2.0	1.1
2,000	19.00	96	0.6	0.7	1.8	0.9
3,000	17.00	96.5	0.6	0.6	1.7	0.8
5,000	15.00	97	0.4	1.6	1.6	0.5
10,000	14.00	97.2	0.5	0.35	1.5	0.45
15,000	13.50	97.32	0.48	0.32	1.38	0.42
30,000	12.50	97.5	0.45	0.30	1.35	0.40

The test for dielectric strength on a turbo-generator is made at 75°C. and consists in the application of a voltage equal to 2 × normal +1,000 for 60 sec. between any terminal and ground or another electric circuit. The insulation resistance must be at least equal to the expression:

$$R = \frac{\text{volts at the terminals megohms}}{\text{rated kilovolt-amperes} + 1{,}000}$$

at the operating temperature.

The Ventilation of Alternators.—In order to keep the temperature of the hottest part of the alternator to 125°C., it is necessary to use forced ventilation on all large turbo-generators.

There are four chief items to be considered in cooling alternators:

1. Quantity and velocity of air.
2. Temperature difference in cooling air.
3. Surface exposed for cooling.
4. Losses to be dissipated.

The air must have velocity to scour out the warm air from the heated parts without regenerative mixing; it must have sufficient

volume and temperature head to remain cooler than the heated parts in all paths through the machine.

The heat that flows in the alternator depends on the difference in temperature in the paths and the conductivity of the paths. The rise of temperature depends on the heat generated and the heat carried away per degree difference of temperature. In the alternator the heat flows according to different laws in the different materials, *i.e.*, iron, copper, air and insulation. The following data, for example, show the stator rise in temperature on a 20,000-kva., 1,800-r.p.m., 13,000-volt turbo-generator based on 100° rise at 100 per cent load:

The cooling air rises 25°C.

Outside surface of core rises 40° and is 15° above discharge air.

Armature copper rises 100°.

There is a drop of about 45° in insulation of armature coils.

The heat conductivity of coil insulation is about 0.003 watt per inch cube and the thickness of insulation is about 0.25 in. The heat generated in the coils is about 0.6 watt per square inch. The thermal drop through the insulation of a modern coil is thus

$$T = \frac{0.6 \times 0.25}{0.003} = 50°\text{C}.$$

There are two ways for heat to flow in the alternators: (1 along the coils toward the end turns, or (2) at right angles to the coils through the insulation into the iron laminations. The amount of heat generated is large; for example, on a 30,000-kva. generator at 97 per cent efficiency, 900 kw. must be dissipated as heat and carried off by the cooling air.

Ventilating ducts must be used to secure the dissipation of the heat generated and from 15 to 25 per cent of the total generator volume is used for these ducts.

One cubic foot of dry air weighs about 0.0749 lb. at 70°F. and absorbs 0.0182 B.t.u. per degree Fahrenheit at 70°. In other words, 55 cu. ft. of dry air will be raised in temperature 1° per B.t.u. at 70°F. One kilowatt = 3,415 B.t.u. per degree Fahrenheit at 70°. Then in any alternator

$$\text{Cubic feet of air per minute} = \frac{55 \times \text{kilowatt loss} \times 3{,}415}{\text{difference in temperature of cooling air} \times 60}.$$

For example, suppose 40°F. is the allowable temperature rise of the cooling air on a 30,000-kva. machine having 900-kw. loss. Then

$$\text{Cubic feet of air per minute} = \frac{55 \times 900 \times 3{,}415}{40 \times 60} = 70{,}178.$$

The usual air velocities are from 2,000 to 3,000 ft. per minute. In the above example, if a velocity of 6,000 ft. per minute is used and the air is passed through the machine from one end, the total duct area would be $\frac{70{,}000}{6{,}000} = 11.6$ sq. ft. in cross-section. If the air is passed from both ends of the machine, the duct area should be halved, or 5.8 sq. ft.

The horsepower of the fan motor required to supply the air in horsepower =

$$\frac{5.2 \times \text{inches of water} \times \text{cubic feet of air per minute}}{33{,}000 \times \text{fan efficiency} \times \text{motor efficiency}}.$$

$$\text{For example, horsepower} = \frac{5.2 \times 0.5 \times 70{,}000}{33{,}000 \times 0.6 \times 0.8} = 15 \text{ hp.}$$

If a washer is used which requires an addition in pressure of 1 in. of water then a 45-hp. motor would be needed.

There are two systems used for ventilating turbo-generators: (1) radial, (2) axial. Each has advantages and disadvantages, and it depends on the manufacturer and other conditions as to which is used. In the radial type the air enters from each end along the air gap and goes out through radial ducts in the stator. This system is very good for cooling the rotor, but has disadvantages in cooling the stator and is used on comparatively short machines. The air passes parallel to the edges of the laminations and the conductivity is low transversely across the laminations as compared to the conductivity along the laminations. The axial system uses axial holes punched in the stator laminations. These holes may extend entirely through the machine or to radial discharge ducts in the center of the core.

A new type of ventilation is a combination of axial and radial and might be called multiple radial. This permits stators to be made of indefinite length and a series of air inlets and outlets are used along the length of the core. In the very large units separate motor-driven fans are used for ventilation, instead of the usual shaft-driven fans.

The higher the velocity of cooling air the cleaner the generator is kept, and the greater the rate of heat dissipation, but this is at the expense of power expended in the air fan.

A 30,000-kva. machine has passed through it about 3 tons of air per minute and thus handles an amount of air almost equal to its own weight every ¾ hr. The manufacturer supplies the fans for a unit, but the engineer must attend to its conditioning.

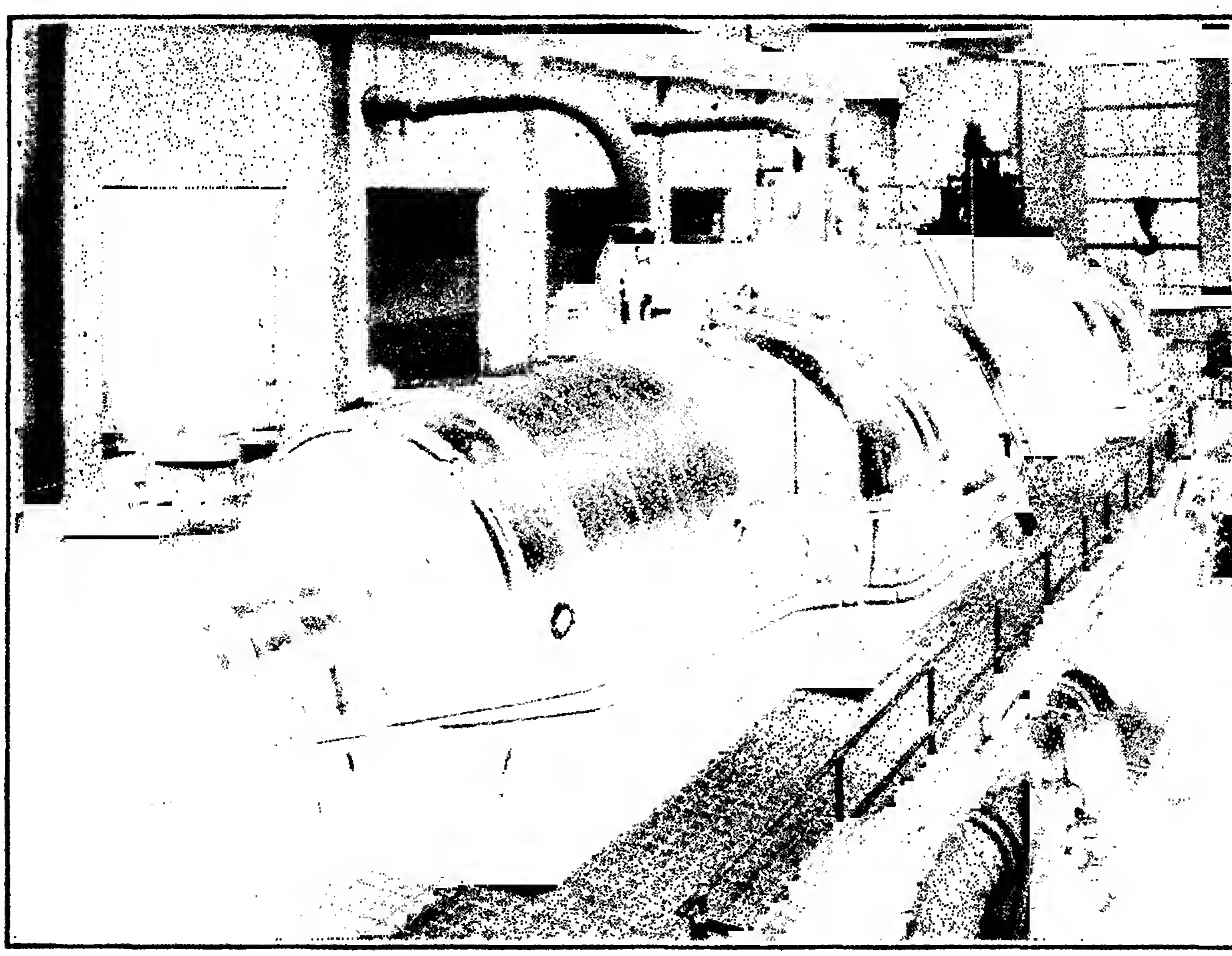

FIG. 139.—Interior of Wabash River station of the Indiana Gas and Electric Company.

If the air is dirty or moist, trouble may arise. For example, if only $\frac{1}{100,000,000}$ of the volume of the air is dust, then a machine using about 70,000 cu. ft. of air per minute handles 1 cu. ft. of dust per 24 hr. If some of this dust is deposited on the windings due to moisture, oil vapor or cavities, the rate of cooling is affected and capacity is lost. At the same time the efficiency is decreased and the insulation may be injured, to say nothing of the expense and delay necessitated by frequently cleaning the machine.

It pays to condition the air for the alternator when the external air is dusty or at a high temperature, and it may even pay, in

some cases, to use the exhaust warm air from the alternator in the boiler draft pit.

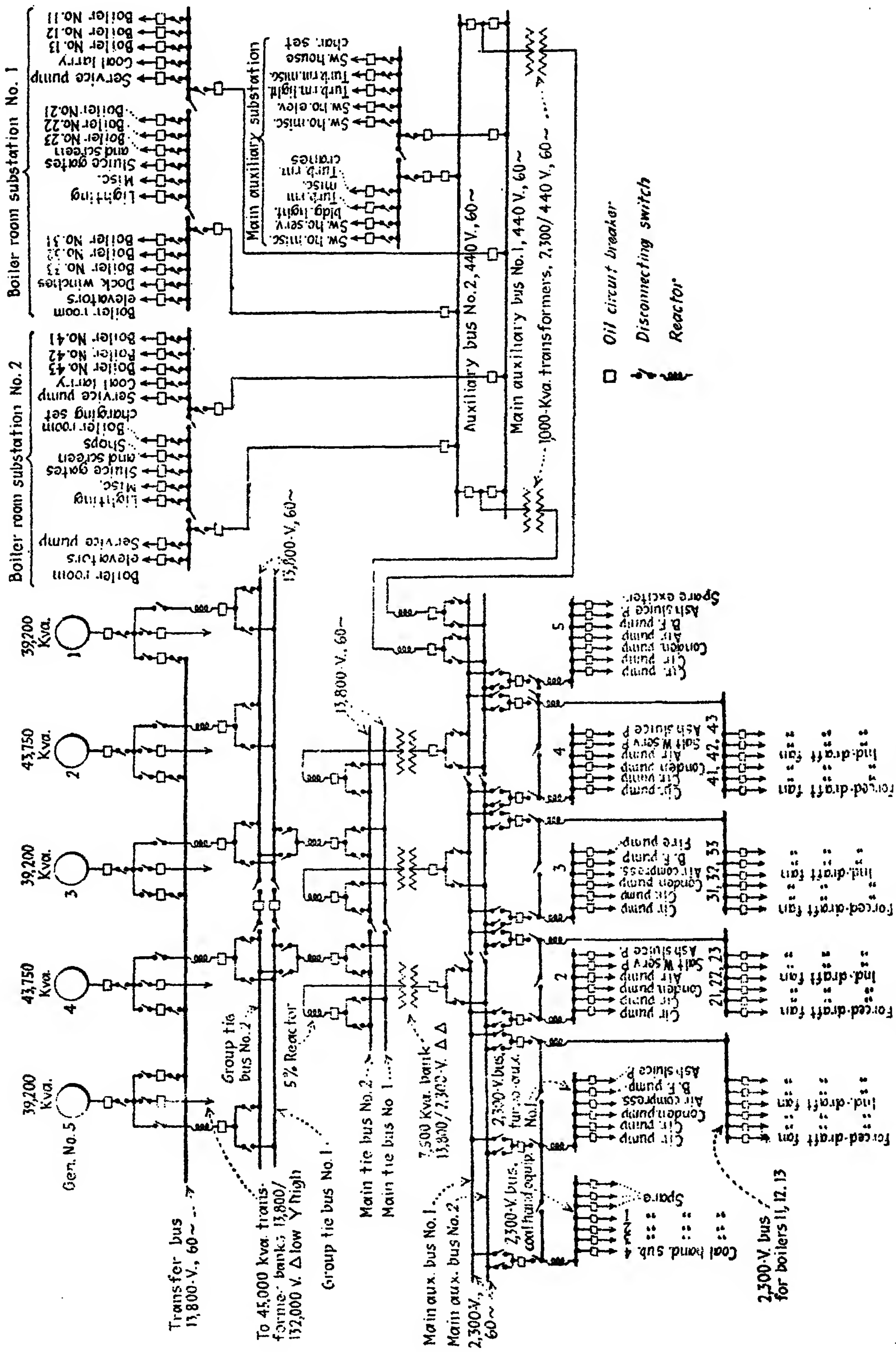

FIG. 139a.—Wiring diagram for the 400,000-kw. Kearny station of the Public Service Electric Power Company.

Air washers have been used to clean the air most frequently, although bag rooms are used freely in Europe. In some installations in this country each generator has a self-contained cooling

and washing system. The air circulates continuously and is sprayed after leaving the generator. Dampers permit control of the volume of air and in some cases the condensate is used for washing and cooling the air.

Closed air-cooling systems are used on large units with closed-type fin-tube coolers to remove the heat losses. These coolers may be cooled by condensate, but the trend is to use the raw circulating water. This system makes a self-contained unit which is compact and lessens fire hazards.

The use of hydrogen gas for cooling alternators has been proposed. Windage and other losses are decreased and hydrogen has seven times the thermal conductivity of air. It is non-explosive unless 30 per cent of air is present, but mechanical difficulties have been encountered in retaining the hydrogen in the generator, as it diffuses very readily.

For extinguishing fires in alternators steam, water and CO_2 gas are used, depending on conditions. In general, steam is the best means and steam lines should be permanently installed to the alternators.

Under operating conditions the limiting factor in determining the capacity of a generator is the temperature, and the thermo-couples placed in the stator slots should be connected to the switchboard to indicate the internal-heat conditions. The thermo-couples can be adapted to control the blower on the generator through relays connected to the driving motor of the blower. They can control the tripping of a circuit breaker or can simply be connected to a recording meter or to an indicating meter to furnish the operators with a record of the temperature conditions. These temperature indications often prove invaluable for determining the reason for the breakdown of a generator.

Parallel Alternators.—In a central station three things require parallel operation of alternators:

1. Limitation in available size of units.
2. Economy in plant operation under variable load.
3. Continuity of service.

The largest single-shaft turbo-alternator is rated at about 50,000 kva., and consequently a large system must use several units in parallel or compound machines to carry the load.

The load on a plant usually varies through wide ranges and, as a machine, both from the electric and steam standpoints,

operates at maximum efficiency at full load, economies are obtained by having available several machines in a plant. Another element is that machines of different makes and ratings can be used on the bus to carry the load so that additions to plant capacity are possible with little change in plant installation. Continuity of service can be more readily maintained in the event of a failure in any alternator because another can be put in parallel on the bus.

When operating in parallel, alternators must satisfy the following conditions:

1. The same frequency.
2. The same voltage at the point of paralleling.
3. Their voltages must be in phase opposition with respect to each other but in phase with respect to the bus load.

There are three operating variables which can be studied with respect to the parallel operation of alternators:

1. Excitation of each machine.
2. Turbine governor control on each machine.
3. Load changes.

The excitation of each machine controls its internal induced voltage and power factor and influences the bus voltage. It does not control the portion of the bus load shared by the alternator to any degree unless there is a large impedance between the parallel units.

The governor control on the turbine permits remote control of the portion of the bus load carried by each machine and maintains the system frequency. A secondary effect is to insure stability in parallel operation through the fact that the speed-load characteristic of the governors is such that the speed tends to decrease as the load increases.

Changes in the load, as regards its constants, influences the system power factor, frequency and bus voltage. The use of automatic voltage regulators for the excitation circuits has made possible automatic control of the bus voltage under predetermined conditions.

The power developed by each alternator, for a given steam input, depends on the induced voltage, the current and the power factor. The external load power developed is determined by the terminal voltage, the current and the power factor. The induced voltages, ratings and constants of alternators in parallel may differ and the machines may still have the same terminal

voltage because the internal impedance drop produces an equalizing effect.

Governor-speed Characteristics.—A governor, since it is a mechanical device, has a certain sensitiveness to changes which control its action. The governor on a turbine must not be sufficiently sensitive to react instantly to instantaneous load surges on the electrical system but still must be sufficiently sensitive to control

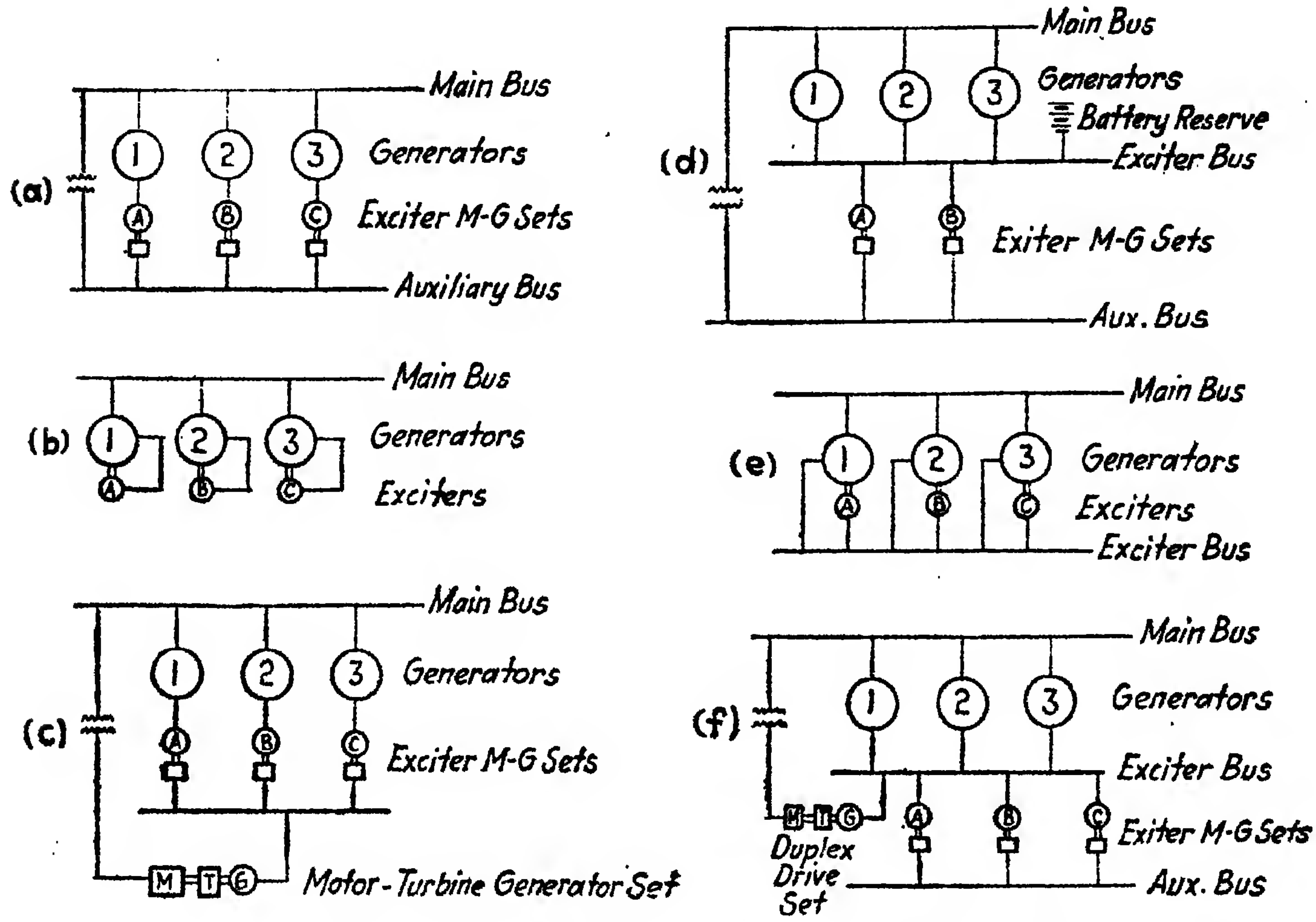

FIG. 140.—Typical excitation systems for power station.

a. Individual system with separately drive exciters. A modification of this system uses a house turbine to supply the auxiliary bus in addition and the auxiliary bus may or may not be used as a house service bus.

b. Individual system with direct-connected exciters.

c. Individual system with reserve through a duplex drive unit connected to the auxiliary bus.

d. Common bus system with individual drives for exciter units and with a battery in reserve. Variations may be had with turbine-driven exciters or the auxiliary bus may be energized by the house turbo-generator.

e. A common bus system which used direct-connected exciters. A battery reserve with or without boosters may be added.

f. Common bus system with a turbine motor-generator set as a reserve supply. Variations are direct drive and duplex drives for reserve.

the division of load as the system load changes. It must also afford opportunity, at the will of the switchboard operator, to permit non-automatic load adjustments and frequency control. A solenoid or motor-controlled main or auxiliary valve permits control of the steam admission, but it is sometimes essential to change the governor-speed characteristics, and consequently the load, by remote control.

For example, if the total load is 30,000 kw., each machine carries an equal amount at a frequency of sixty cycles. At

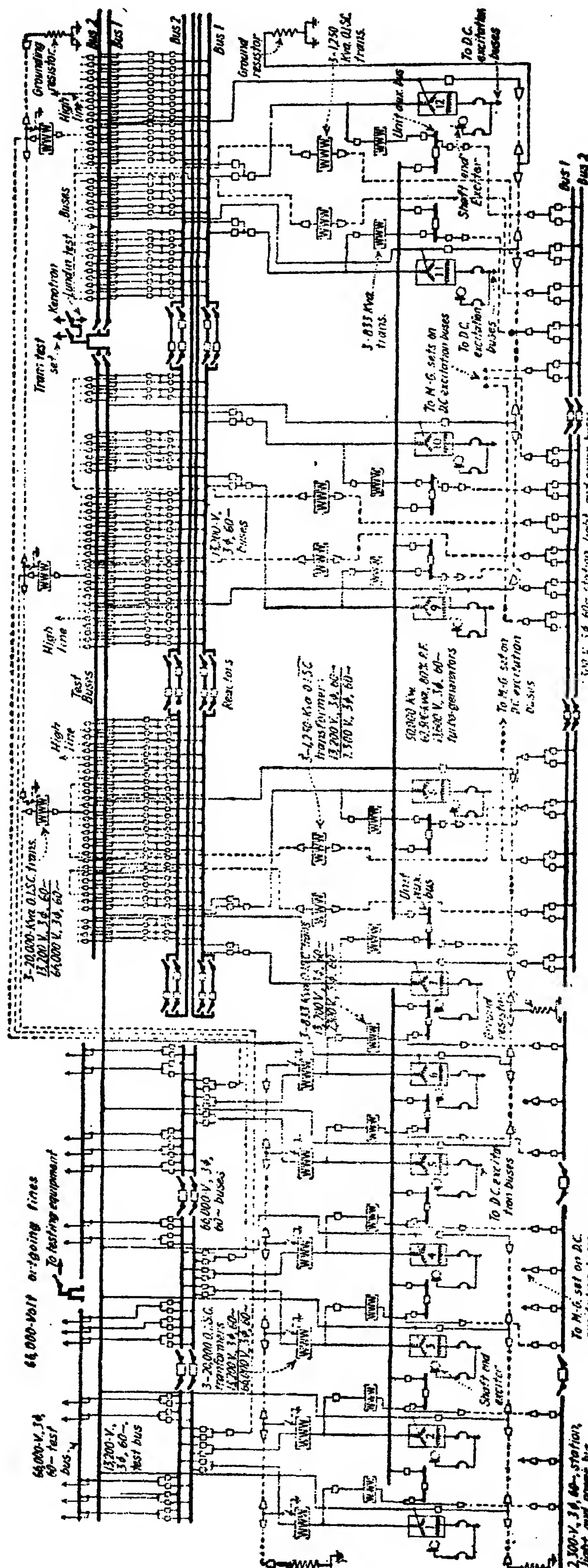

FIG. 141.—Electrical layout for Richmond station of the Philadelphia Electric Company.

fifty-nine cycles one machine carries a load of about 22,000 while the other has a load of 25,000. Through governor control, however, the characteristic of No. 2 machine can be raised or that of No. 1 lowered until each carries the same load at fifty-nine cycles. If each governor is raised and adjusted, the machines can be made to carry the same and equal loads at sixty cycles.

In steam engine operation the sensitiveness of the governors may cause trouble due to the cyclic variation in torque per revolution due to the reciprocating motion but the turbine has a uniform torque per revolution and the governor can be made more sensitive to changes in operating conditions.

In a given plant the frequency can be controlled by automatic governing of one machine which is always connected to the system. Any change in system frequency caused by change in load division or change in excitation conditions can be counteracted by this automatic governing of the one unit. The effect of change of load on one unit on system frequency is largely a function of the capacity of the machine as compared to the total load on the system. A small alternator, from no load to full load, affects the system frequency but little from any action of its governor. In a two-unit plant of such a capacity that each unit has equal rating, the effect of putting a unit on the load or the effect of a variable load or of the governor of a unit is very marked and must be controlled by automatic governor control or by hand governor regulation. Also a plant having modern units of similar governor characteristics has little trouble in controlling system frequency independently of load variations as compared to the type of plant that has grown up as the load increased yearly and which contains units of different makes and designs. In such a plant only a mean governor adjustment can be made for the individual units and the other adjustments under variable load conditions involve hand operation or automatic governor control on a large unit which acts as a stabilizer for the others.

Effect of Excitation.—The excitation of any machine is subject to the control of the plant operator, even though a voltage regulator is used. The effect of a change in excitation depends on the conditions of operation and the magnitude and electrical constants of the system. In general, a change of excitation affects the magnitude of the bus voltage, the induced voltage of each machine and the internal power factor of each machine. A secondary effect, under certain conditions, in a change in system

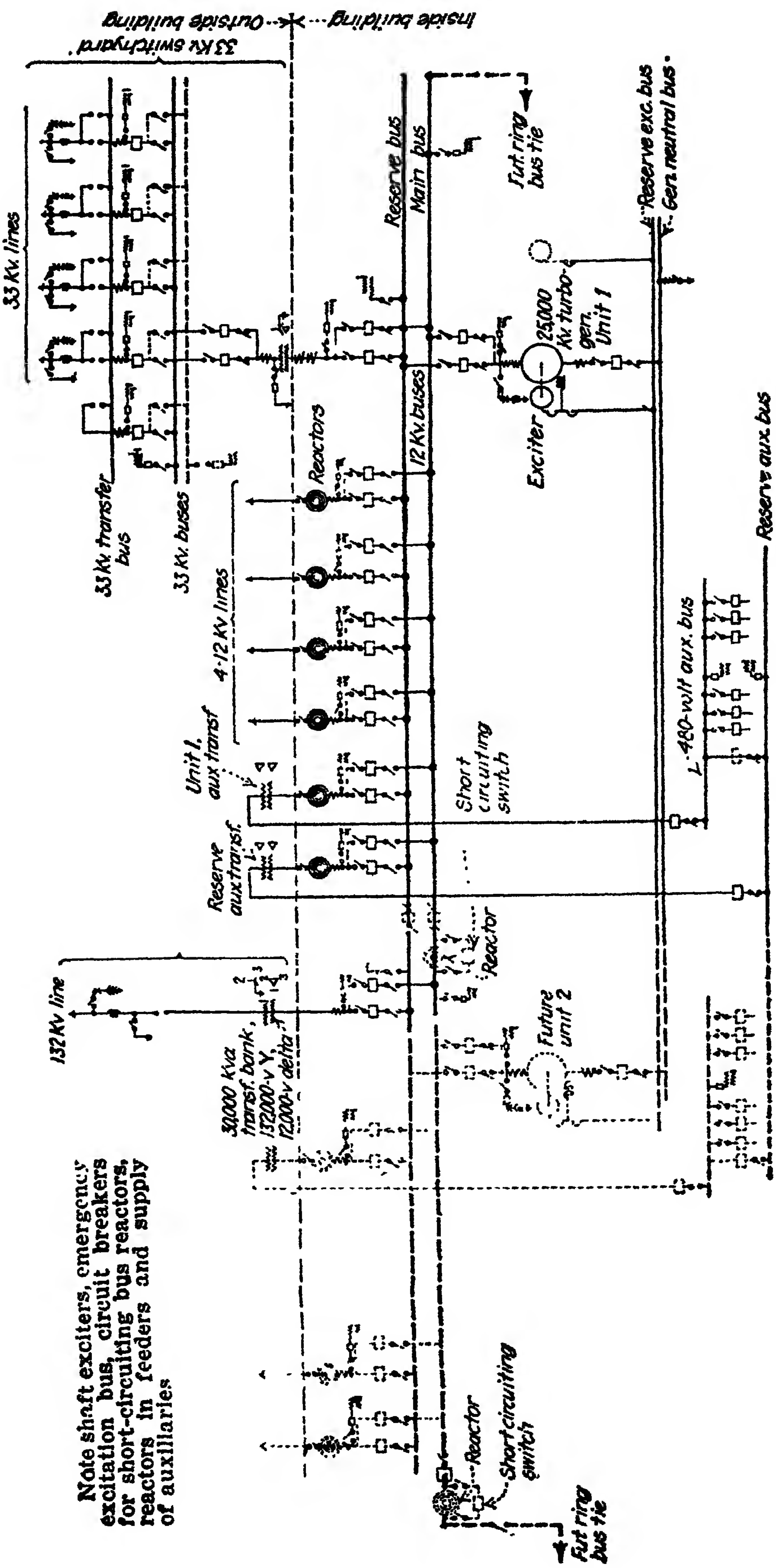

FIG. 142.—Electrical layout and protective arrangement for Waukegan station of the Public Service Company of Northern Illinois.

frequency and in the internal power developed by the individual machines. The relative speed of the parallel alternators is fixed, so that a change in excitation cannot change the load except as the phase shift and the increased magnitude of armature copper loss changes the power delivered to the external circuit. When alternators are paralleled through transmission lines or bus reactances a greater effect on load division is produced by

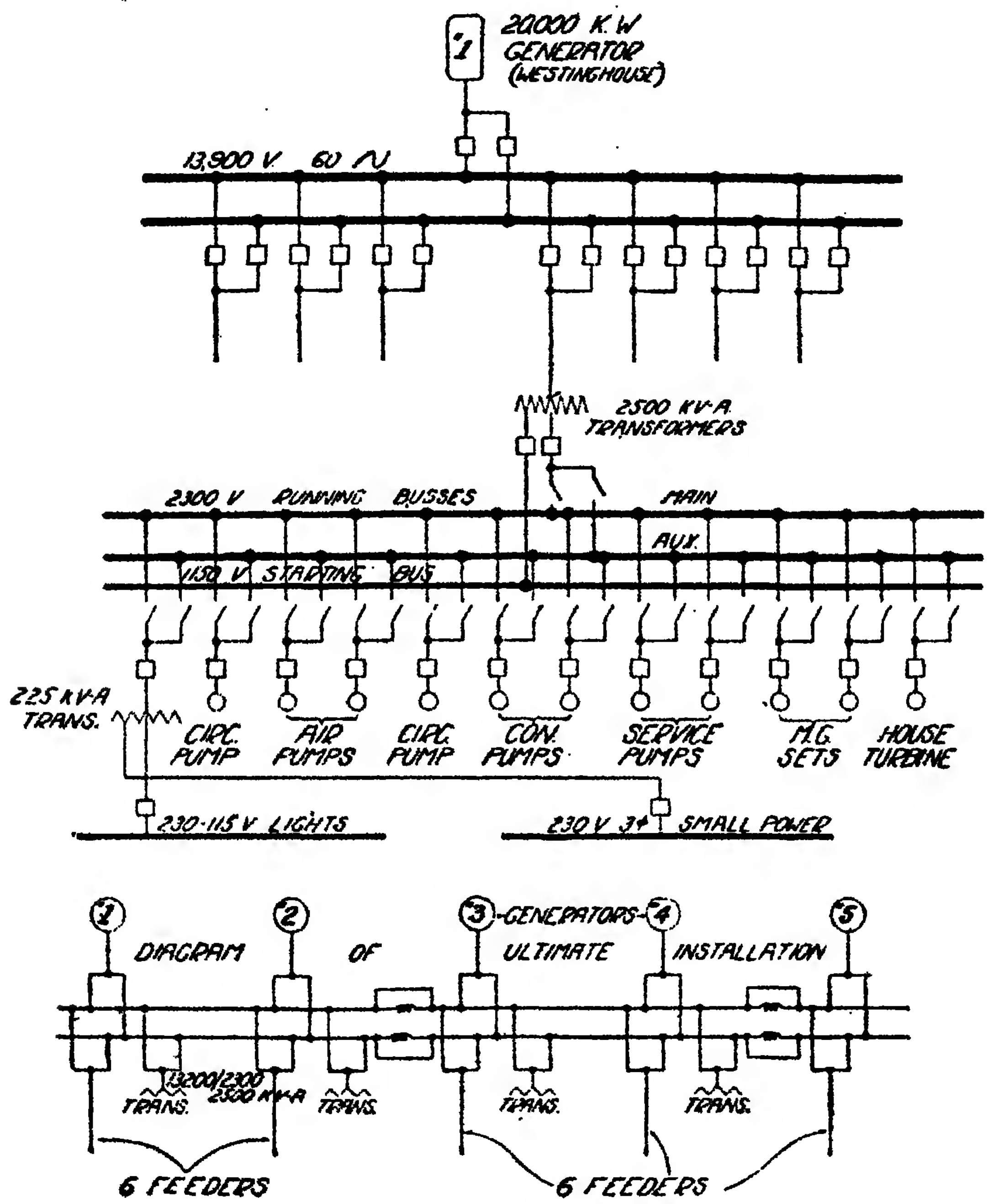

FIG. 143.—Unit layout for the Barbadoes Island station of the Counties Gas and Electric Company.

excitation changes because the external constants of the circuits are of appreciable magnitude.

EFFECT OF STEAM CHANGES

When one alternator is connected to a system having large capacity with automatic control of bus voltage and system frequency, the effect of increased steam admission is simply to cause a sudden jump ahead of the conductors and a consequent phase shift until the increased current and the resultant electrical

power balances the applied power. The armature revolving in the field might thus be considered a flexible coupling which has a slight play and is controlled by the applied mechanical power or by the field flux. Increased load means a tightening of the coupling, while increased excitation, over normal, means a loosening of the coupling.

In any large system it is very difficult to predict the behavior of parallel alternators from a simple physical analysis, but a complete solution of the problem can be obtained by the use of the system constants. It must be remembered in mathematical solutions, however, that the system constants so called may be variables under different load or transient conditions so that mature judgment and close analysis of every situation or problem are required to obtain a reliable solution.

Grounded Neutral in Parallel Operation.—When Y-connected alternators are operated in parallel there is a difference of potential between their neutrals equal to their vector phase difference at any instant and if the neutrals were interconnected or grounded a third harmonic current would circulate between them. This might be sufficiently large to cause disturbances. If this current is to be prevented the neutral of only one generator at a time can be grounded.

Whether the neutral should be grounded in any case depends on operating conditions:

1. If uninterrupted service is the essential condition—never ground.

2. If voltage strains are limiting conditions—always ground.

3. If selective action is needed for system protection and control—ground through a resistance.

The use of a resistance in a ground connection is often questioned, although it limits the current on one phase in case of a short on the phase. It, however, gives no great degree of voltage-strain-limitation protection. Reactance instead of resistance in the ground connection may introduce high-frequency surges and is little used. Of late many systems have used a ground through a resistance in order to secure protection and selectivity in control.

In all cases of grounding a true ground must be obtained and maintained or very dangerous conditions may arise because line potential is brought into proximity to operators. When an overhead ground wire is used in connection with the transmission

line, it affords opportunity for maintaining a better ground connection by connecting the ground wire and the station ground.

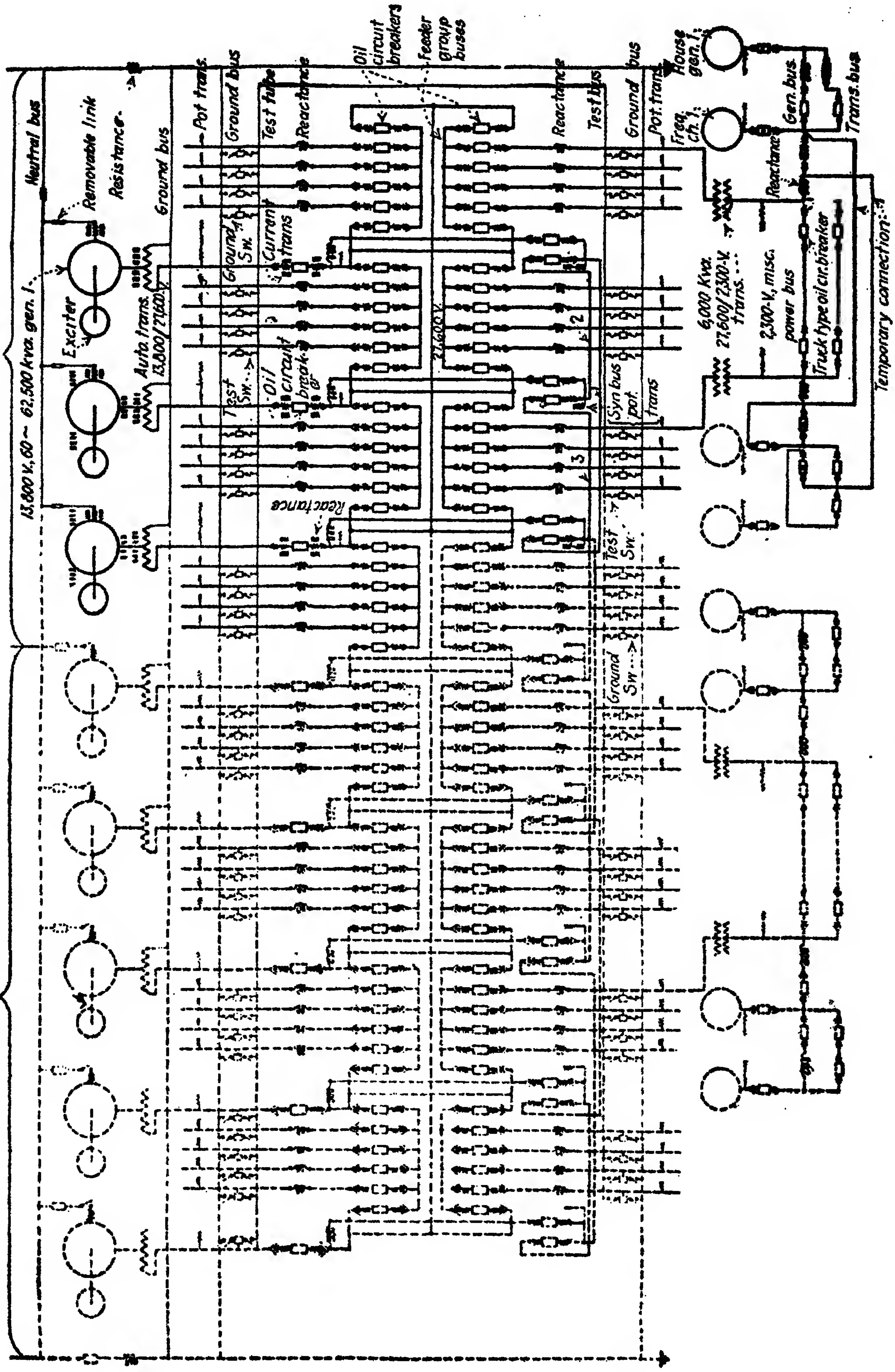

FIG. 144.—Electrical layout of the Hudson Avenue station of the Brooklyn Edison Company. Unit feeding of a group of feeders is normal practice.

Quantitative Treatment.—In order to treat, in a quantitative manner, the parallel operation of alternators on a bus, it is necessary to derive the mathematical expressions involved. The

derivation is based on alternators in parallel on a bus in one station without any appreciable bus reactance or resistance. The machine constants are assumed to consider all resistance and reactance to the point of paralleling. Vector algebra is used throughout and a more extended treatment will be found in the text of Professor R. R. Lawrence.[1]

E = bus voltage, I = load current, total, Z = external load impedance $= R + jX$. $I = \frac{E}{Z}$, W = internal power, P = external power.

I_1, I_2, I_3, etc. = alternator currents.
e_1, e_2, e_3, etc. = induced voltages per alternator phase.
r, x, and z = alternator internal constants per phase.

All values will be considered phase values.

$$I = \frac{e_1 - E}{z_1} + \frac{e_2 - E}{z_2} + \frac{e_3 - E}{z_3} \text{ etc.} \tag{1}$$

and

$$E = \frac{e_1(z_1 + z_2 + \dots)}{z_1} + \frac{e_2(z_1 + z_2 + \dots)}{z_2} + \frac{e_3(z_1 + z_2 + \dots)}{z_3} - I(z_1 + z_2 + z_3 + \dots) \tag{2}$$

also

$$I_1 = \frac{e_1}{z_1} - \frac{1}{z_1}\left[\frac{e_1(z_1 + z_2 + \dots)}{z^1} + \frac{e_2(z_1 + z_2 + \dots)}{z_2} + \frac{e_3(z_1 + z_2 + \dots)}{z_3} - I(z_1 + z_2 + z_3 + \dots)\right] \tag{3}$$

Equation (3) is the general equation for the current in any one alternator when connected in parallel with others to a bus having no impedance.

If all the generated voltages are equal, Eq. (3) reduces to

$$I_1 = \frac{(z_1 + z_2 \dots)I}{z_1} \tag{4}$$

or the current divides between the machines in the ratio of the total impedance to the impedance of the single machine.

In two similar alternators having equal constants and operating in parallel, Eq. (3) reduces to

$$I_1 = \frac{(e_2 - e_1)}{2z_1} + \frac{I}{2}. \tag{5}$$

[1] LAWRENCE, R. R., "Principles of Alternating Current Machinery," McGraw-Hill Book Company, Inc., New York.

In the general Eq. (3), if the circulating components are due to a difference in magnitude of the generated voltages, they equalize the terminal voltages through armature reaction and Iz drops, but if the components are due to the generated voltages being out of phase, they tend to produce synchronizing power to bring the machines back in phase as well as to equalize the terminal voltages. In the event there is a power-limiting reactance in the bus sections, this reactance (X) must be considered in determining the current in each alternator.

Any circulating component of current I_c that tends to be present when two alternators are in parallel has a magnitude equal to the vector difference in the generated voltages e_c divided by the total impedance in the short-circuit path formed by the bus reactance X and the armatures.

$$I_c = \frac{e_1 - e_2}{2z_1 + X} = \frac{e_c}{2z_1 + X}. \tag{6}$$

If such a circulating current could exist it would produce generator action on one alternator and motor action on the other and on the basis of the tendency for such an energy interchange, and its effect on producing phase displacements and circulating currents, the synchronizing power of the alternators may be explained. The synchronizing power is greatest for inductive loads on constant voltage systems.

In terms of the terminal voltage E before hunting occurs the synchronizing power for two identical alternators is given by the equation

$$P = \frac{E^2}{2}\left[\frac{x}{z^2} + \frac{(x^2 - r^2)}{2z^2}\,\frac{X}{(R^2 + X^2)} + \frac{Rrx}{z^2(R^2 + X^2)}\right]\sin\alpha, \tag{7}$$

where α is the angle between I_c and e_c and X and R are load constants. The first term of Eq. (7) is the most important and the second becomes zero for unity power factor in the load.

Under short-circuit conditions on one alternator the synchronizing power reduces to zero and the alternator falls out of step. Let R and X equal the load constants and α the angle between the generated voltages of two alternators in parallel.

Then the synchronizing power between two identical machines is

$$P = \frac{e^2}{2}\left[\frac{x}{z^2} - \frac{2X + x}{(2R + r)^2 + (2X + x^2)}\right]\sin\alpha. \tag{8}$$

where e is the generated voltage. At short circuit, since R and $X = 0$,

$$P_1 = \frac{e^2}{2}\left[\frac{x}{z^2} - \frac{x}{z^2}\right] \sin \alpha = 0.$$

The synchroscope indicates the proper phase relations and frequency for paralleling alternators. It is used with or without lamps as an additional check on conditions. It has been modified in many ways and can be used as an indicating instrument with a ticker and tape attachment whereby a record is obtained of the efficiency of the operators.

The synchroscope is really a small motor with a laminated field structure. The field is excited, through step-down potential transformers and a resistance, from the main bus. The armature has two windings displaced 90 deg. in space and is connected to the generator which is to be paralleled on the main bus. One of the windings is connected through resistance, the other through reactance to potential transformers which, in turn, can be connected to the generator synchronizing bus by means of a receptacle or switch.

The armature shaft has a needle mounted at the face end of the device and will always take a position such that the axis of the field produced by its windings will coincide with the axis of the field produced by the field winding excited from the main bus when the latter is a maximum. The needle will take a corresponding position on the face of the instrument. The reactance winding on the armature has a current in space and time quadrature with the current in the resistance winding on the armature and with the generator voltage. The field current is almost in phase with the bus voltage because of the series resistance. If the generator and bus voltages are in phase, the current in the field and in the resistance winding on the armature will be in phase and the armature will rotate until the fields have the same axis. For 180-deg. phase the same position will be taken as regards fields but the needle will indicate a reverse direction. If the generator and bus voltages are in time quadrature, the reactance winding will take the position formerly taken by the resistance winding. At intermediate voltage conditions the armature will take a position such that the needle indicates an intermediate position. Thus, as the generator to be paralleled is adjusted for paralleling, the armature of the synchroscope and its attached needle will indicate phase difference by its position and frequency

difference by its rotational speed. When properly connected, the needle indicates accurately the moment for closing the main switch which parallels the generator on the bus. (Fig. 133).

Generator Protection, Excitation Systems and Control Circuits.—Continuity of service is the keynote in all operation, and protective devices should function to secure this condition by:

1. Isolating faulty portions of a power system, without disturbing service, when trouble arises.
2. Operating only when the magnitude of the disturbance is sufficiently great to endanger equipment.
3. Operating only when the time duration of the trouble is sufficiently great to endanger equipment.

The protection of equipment should largely be considered in its design because the less auxiliary apparatus and wiring used in connection with any piece of equipment the less the opportunity for trouble, because the auxiliary wiring and devices in themselves introduce new hazards.

The generator is the primary device in power production and must, of necessity, be disconnected from the power system only as a last resort. Also it is operating in the plant where operators observe its condition at frequent intervals and can control it and change load conditions very quickly. Another element is that in generator design the protective element can be incorporated to a great degree without changing costs, efficiency or performance characteristics to any great extent.

Reactance is one great source of protection in generator design. It is essential for stable parallel operation and at the same time acts to choke out current when short circuits occur. It is far greater in value than resistance in most generators and in some slow-speed water-wheel units is so large as to hold down the current under short-circuit conditions to about 2.5 times normal full-load value. Temperature indicators, high-grade insulating materials and field control also protect the generator.

Under short-circuit conditions the current for the first few cycles may be very much greater than the sustained value at the end of the transient period. This immense current and its flux may react on the direct-current field circuit to accentuate the effect since the field has an induced voltage from the armature that, in accordance with Lenz's law, tends to maintain and even to increase the induced voltage in the armature. This results in the advisability of incorporating in the main protective

device an auxiliary device which will open the direct-current field circuit.

Another element in generator protection is the fact that the induced voltage available to produce a short-circuit current will depend in magnitude upon the part of the winding in which a short circuit or ground occurs. For example, in a Y-connected

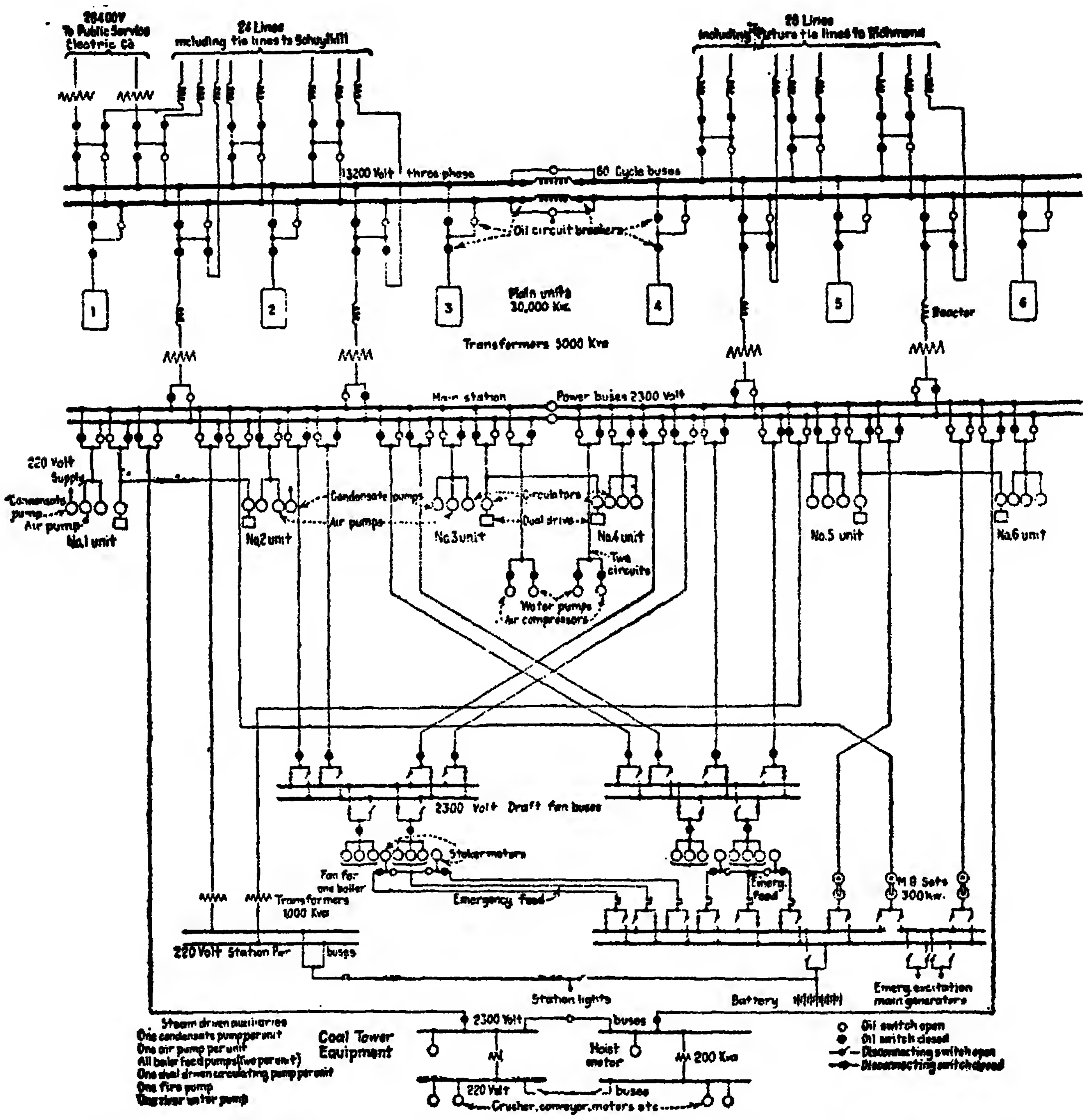

FIG. 145.—Electrical layout for the Delaware station of the Philadelphia Electric Company.

generator with neutral grounded a ground at the end of the winding (toward bus) would have full-phase induced voltage back of it, but if the ground occurred near the neutral the phase induced voltage would be small in magnitude because but few turns produce a voltage of magnitude and direction to force current through the ground circuit. Also in the operation of generators in parallel, trouble on one unit will cause the other units to pour

their kilovolt-amperes into the fault unless proper precautions are taken.

Usual practice and conditions of service require the generator to remain connected to the bus unless the trouble is very great or unless the machine can be disconnected readily without disturbing the system service.

The generator usually is connected to the bus by means of a motor or solenoid-operated oil breaker or switch which has a solenoid trip coil circuit. The auxiliary protective devices function to energize the tripping solenoid on the oil breaker by closing contacts which permit a direct-current circuit to flow to the trip coil on the solenoid or alternating current to flow to the trip solenoid in the alternating-current trip type of breaker or to ring a bell alarm to attract the attention of the operators or to remove excitation from the generator in trouble. These auxiliary devices must be actuated by the main generator alternating-current lines and are called relays. They are of several types and may have time adjustments for instantaneous action, definite time action or action whose time is inversely proportional to the magnitude of the disturbance. Incorporated with these relays, an auxiliary relay is often used to open the field of the generator.

The general types of protective devices may be outlined as follows:

1. Overload
2. Directional
3. Leakage
4. Reactance
5. Temperature
6. Balanced

or combinations with instantaneous, definite or inverse time settings.

The best method of protecting a generator on a grounded system is to bring out both ends of its winding so that balanced protective relays may be used. This gives protection from one end of a generator winding to the breaker leads for all sources of trouble that may occur except early faults between turns of the same winding and yet insures the generator remaining on the system under all other operating conditions. Current transformers are placed on the two ends of each phase winding and the secondary circuits of the current transformers in each phase are connected in series with a special relay connected across the secondary wires of each phase. Normally, no current flows in

the relay, but if a fault occurs a current unbalance sets up a secondary current through the relay which will operate at a predetermined time and degree of current magnitude to trip the generator from the circuit. An auxiliary switch on the main breaker in turn actuates the field switch on the generator and removes the excitation.

In some stations the transformer bank and the generator are considered a unit and balanced overall protection is used, but in other cases both the generator and the transformer bank have balanced or differential protection. And the transformer

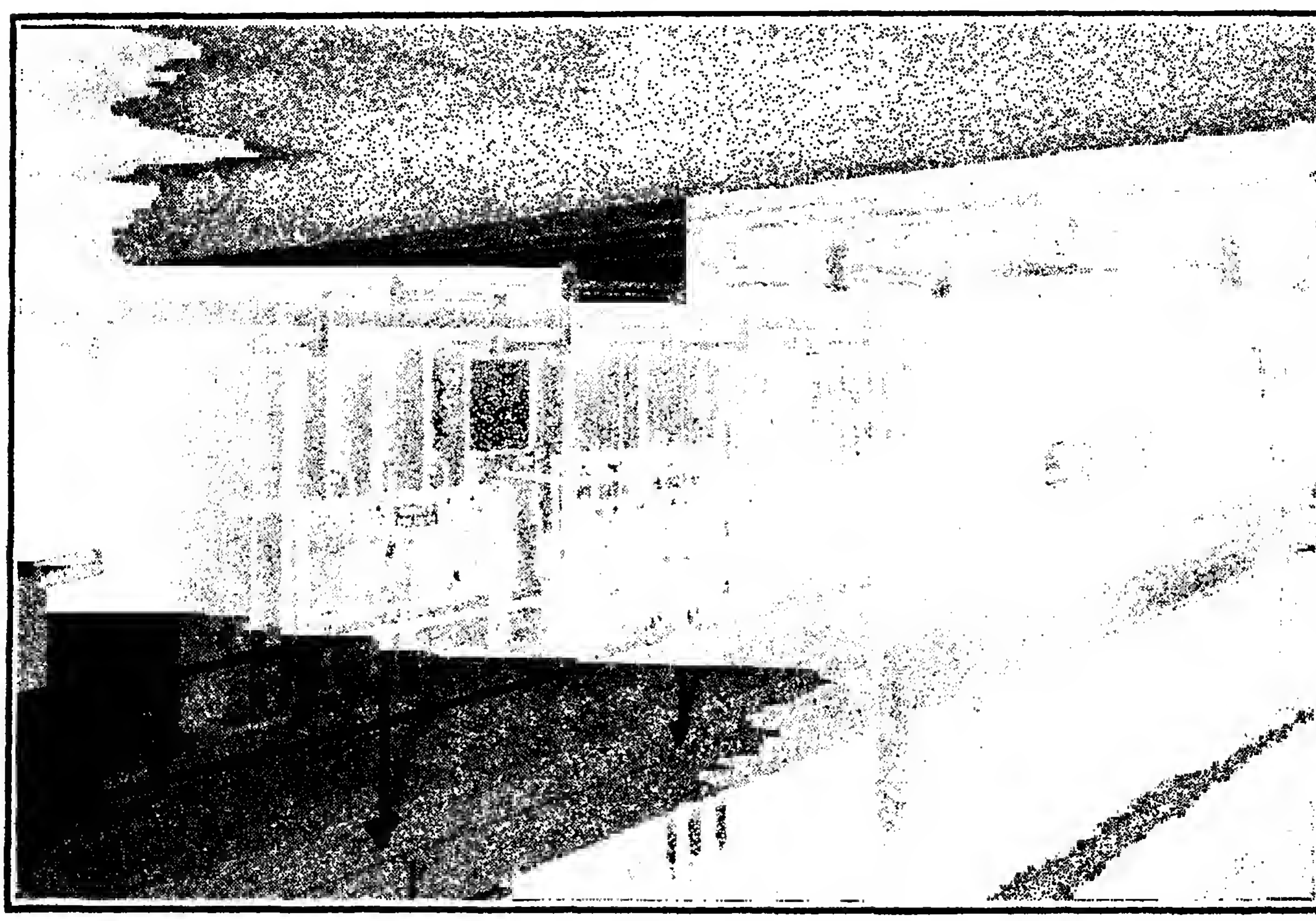

Fig. 146.—A house-service gallery in a modern station.

bank nearly always is provided with a definite time-limit relay of the induction or thermal type to care for overloads.

This type of balanced or differential protection can be made to operate on very small unbalanced current and thus is superior to the directional or reverse-energy type of relay protection used where the ends of the phase windings are not available. For overload conditions on a generator, definite time relays may be used, but operators generally prefer to have non-automatic operation of breakers when overloads occur.

With the balanced protection system, in order to balance each circuit and to adjust each relay a set of compensating coils or auto-transformers are sometimes used, in which case each

secondary transformer-circuit relay and compensating coil forms a separate circuit.

The protection of the generator by temperature relays involves the use of thermo-couples and a relay that is actuated by a change in temperature. This relay closes a bell alarm or lamp circuit which attracts the attention of the operator to the machine. All large machines have thermo-couples installed and the temperature readings and the temperature relay are splendid supplementary protective devices which care for all normal overload protection.

External reactors are used but little in generator circuits for protective purposes, but the bus layout reactors are used to advantage to sectionalize the bus and limit the transfer kilovolt-amperes in parallel operation. In neutrals of generators, reactors can be used to advantage to protect the individual machines where a grounded neutral system and a ground bus are used.

Excitation Systems.—The excitation system in the power plant is one of the most important, as the whole plant operation is tied up to it. The object in installing an excitation system is to get the simplest, strongest and most reliable system for the given plant at a reasonable cost. Too many controls and refinements only add another weakness—the general principle is to install a few independent units in such a manner that excitation cannot fail under any condition.

Exciters should be specially designed machines of the shunt non-interpole type which are worked at low densities and yet give stable voltages. The exciter units may or may not have automatic voltage regulation. The exciters must be designed to give a quick response to the regulator control to prevent regulator hunting and must be stable as regards voltage to prevent voltage fluctuation. At the same time if the magnetization curve is a straight line, an unloaded high-capacity line may cause overexcitation of the alternator connected to it and give rise to voltage instability in the exciter.

The excitation capacity should be sufficient to excite all the machines in the plant under conditions of maximum load and minimum power factor. It is usually based on maximum load at 80 per cent power factor and about 20 per cent is added for variations. The amount of reserve can be determined only for the individual case. In some cases the maximum size of the exciter is determined by the rating of the largest alternator and

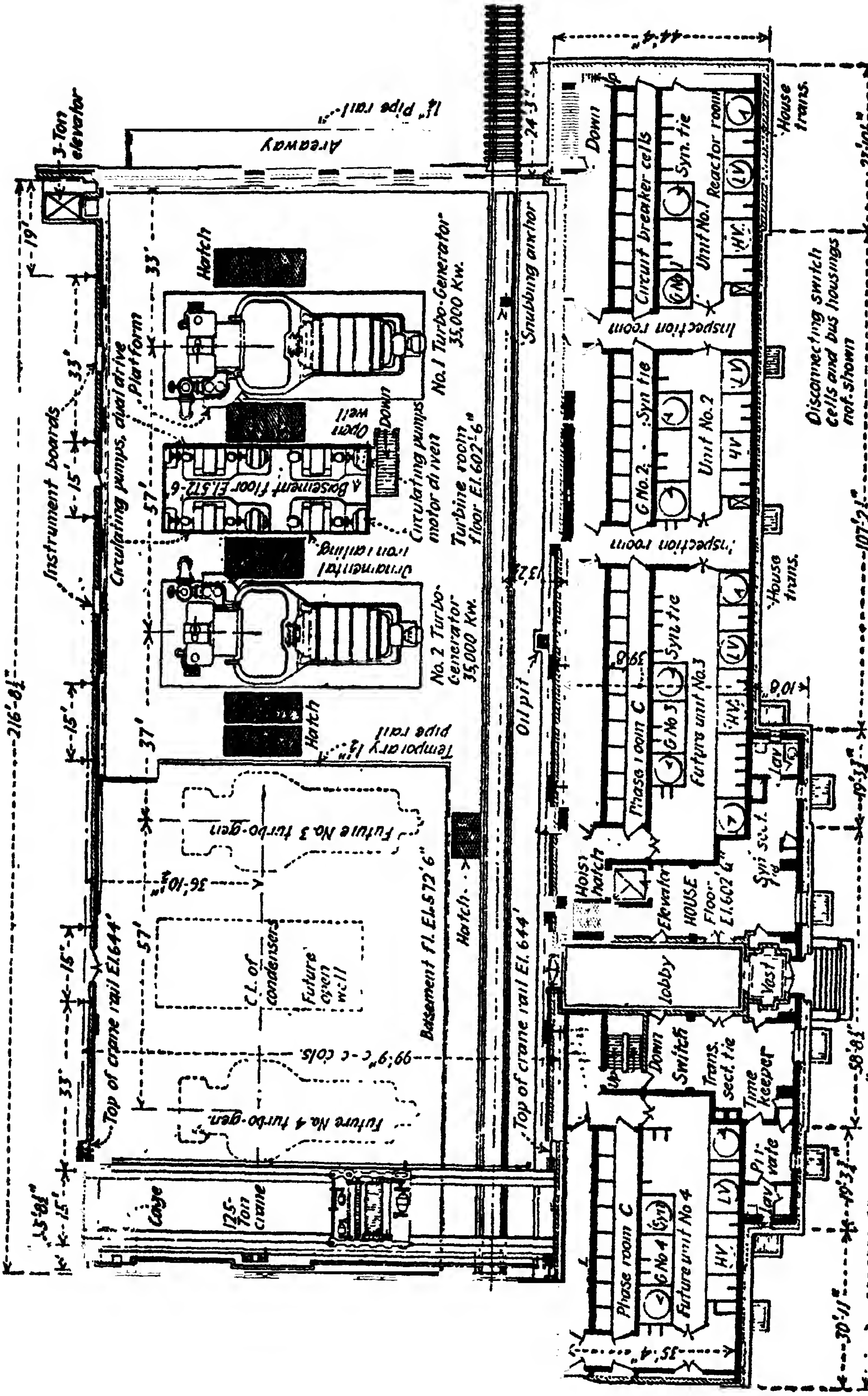

FIG. 147.—General plan of turbine room and switch house of the 300,000-kw. Avon station of the Cleveland Electric Illuminating Company.

in others the largest exciter is to carry the entire plant excitation. This practice will vary with the system of excitation used.

The two standard exciter voltages are 125 and 250 and the latter is preferred for large plants, as the higher voltage means less cost and less complication with increased reliability in operation. When the excitation current gets to a magnitude of about 800 amp. there is great difficulty in getting proper brush action so that 250-volt excitation is better. Even higher excitation voltages are projected as feasible. The range of voltage required on the individual exciter may be as great as 3 to 1 and the voltage regulator or field rheostat must care for this condition. The shunt-wound exciter is preferred to eliminate reversal of polarity and to simplify the operation of parallel exciters.

A fundamental idea in the installation of an excitation system is to consider the future growth of the plant and changes in the design of machines. Flexibility and room to expand are primary considerations.

The percentage excitation usually necessary for a given kilvolt-ampere is supplied with machines purchased and the variation of field current, etc. under load conditions can be determined.

Three Types of Excitation Systems.—There are three general excitation systems used in this country:

1. Common bus system.
2. Individual exciter system.
3. Combination or duplex system.

In the common bus system of excitation all the alternator fields are connected to a common excitation bus. The voltage on each machine may or may not be controlled by an automatic regulator having multiple control contacts. In some cases duplicate exciter buses are used to give increased reliability and flexibility, but this practice is questioned. Frequently, a battery reserve is used on the exciter bus as a reserve to maintain the excitation on the system for from 10 min. to 1 hr. when normal excitation fails. When a battery is floated on the bus and automatic voltage regulation is used, series boosters are needed. The advantage of the common bus system lies in the fact that it concentrates the excitation in a few large machines, results in small space and few cables and is simple in operation under normal conditions. The disadvantages lie in the fact that the system is inflexible, complicated and unreliable under abnormal

operating conditions and is uneconomical for large stations. A slight degree of trouble on the bus or at any point in the system will cause trouble on the whole system and trouble in the regulator will affect the excitation of all machines. Also it does not lend itself to the unit system of power plant installation and is not flexible as regards changes and developments. This system was an early development and is rapidly becoming obsolete.

In the common bus system the exciters can be driven in many ways. A motor-driven exciter is frequently used and the motor gets its energy from the main bus or from a house turbo-generator. When the main bus is used for the excitation power supply, any trouble on the system affects the exciters and also another excitation source must be provided to start the plant. When separate turbo-generators are available, the excitation is unaffected by system changes but the question of the heat balance and operating economy involved in the use of a small turbine is introduced. In general, it is bad practice to use the excitation bus for any other purpose than for excitation, but in some cases the exciter power supply is used for direct-current auxiliary service. In the common bus system where the exciters are driven by the main units and connected to the excitation bus, any change in conditions at a main unit affects the whole excitation system and the voltage fluctuations are a double function of the speed. Also transient high voltages introduced in the field of any generator may be introduced into the complete excitation system. This system also requires the largest capacity in storage-battery reserve, although it may have the lowest maintenance cost, as few units are used.

Another system is called the "individual excitation" system and it is used very frequently in Europe, and present tendencies in this country point to unit plant design and the individual system of excitation. In this system each generator has its own exciter and regulator or field rheostat.

The exciter may be driven by the generator, by an induction motor supplied from the main bus or house-service bus, or by a direct-connected or geared turbine. In hydro plants usually the exciters are driven by the main generators, and this is also the practice in steam plants of large size. In this system each exciter is large enough to carry one unit and at most two units. The advantages of the system are that it gives greater safety and reliability under abnormal and normal conditions. It tends

toward operating simplicity and is adaptable to automatic and remote control. It involves a small amount of low-voltage power at each main unit and requires the smallest field rheostat for each alternator field. There is no necessity for the use of any rheostat in the alternator field under certain operating conditions and the exciter auxiliary and control apparatus may be located near the main unit, which makes the installation less complicated, more reliable and more economical.

The combination of the common bus system and the individual system has many advantages and the so-called duplex drive for exciters is very good from a reliability standpoint in that excitation is available no matter what happens in the main electrical system. In the duplex drive, for normal operation, depending on heat balance, a motor carries the excitation load, but under a failure of speed a turbine picks up the excitation load. A combination of individual drive with duplex drive for reserve seems to offer most advantages for large systems where reliability and simplicity are primary features.

Some typical excitation systems are shown in Fig. 140 and for specific plants many variations in mechanical assembly and installation will be found. A very economical installation is to locate the exciter field rheostats, the generator field rheostats and the exciter panel very near the generator when using the individual exciter system with the excitation generator on the shaft of the main unit. A late type of installation uses a mezzanine floor just under the main turbine-room floor, as this makes for a minimum of control wiring cost and great operating reliability. Each generator has its own exciter bus and panel with breakers, usually carbon, remotely controlled from the main generator panels and with a remotely controlled motor-operated exciter field rheostat.

Voltage Regulation.—Hand regulation of voltage predominates in large stations supplying metropolitan areas and having automatic feeder voltage regulators. For plants supplying fluctuating heavy power loads and those connected to high-tension lines some form of automatic voltage regulation is used. For the automatic regulation it is customary to use Tirrell types, although motor-operated face-place rheostats are also used. The usual Tirrell type of regulator utilizes an alternating-current control solenoid, a direct-current control solenoid, relays and exciter field contacts. In the KR system of regulation a series booster is interposed between the individual exciter or exciter bus and

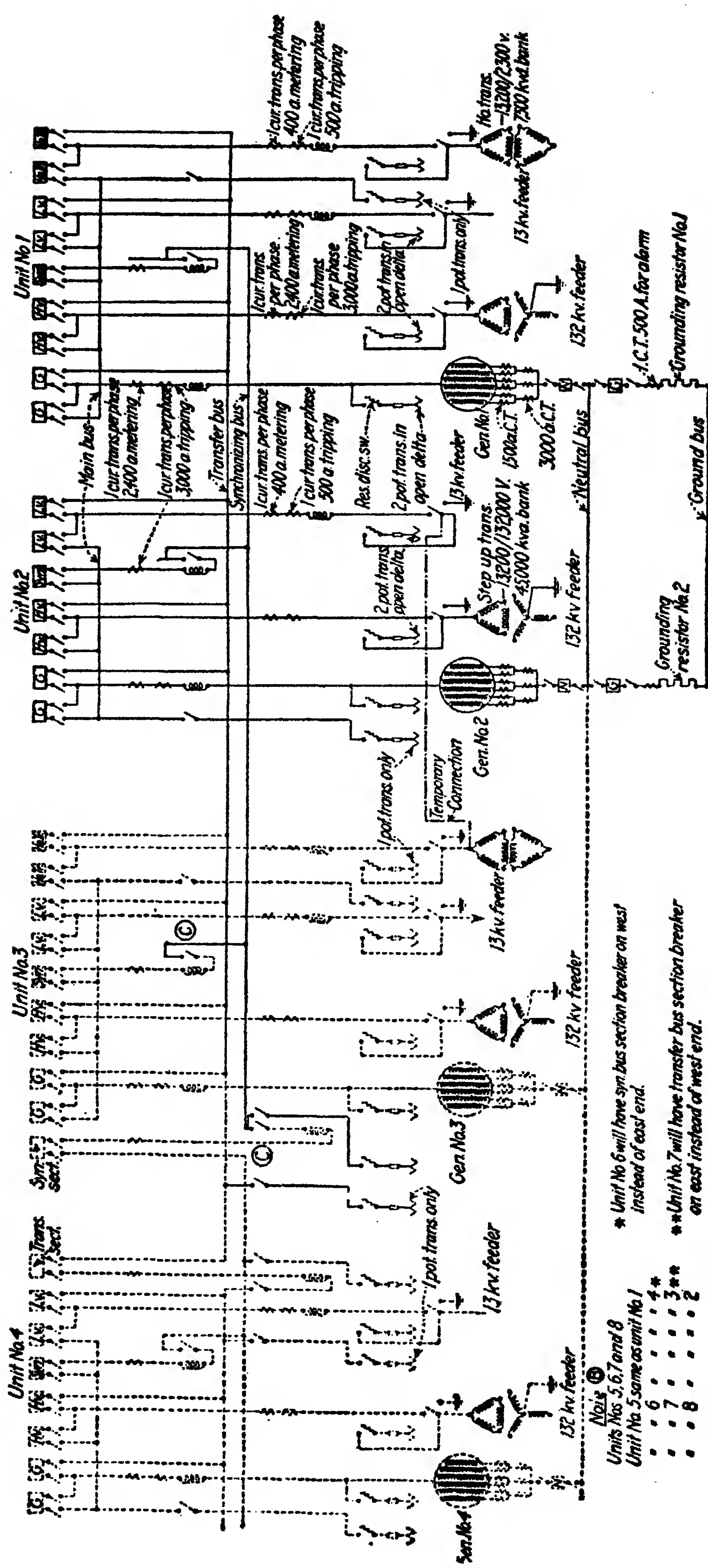

FIG. 148.—Wiring diagram of the 13-kv. circuits in Avon station of the Cleveland Electric Illuminating Company.

the alternator field in order to give a wide range of excitation voltage.

Control System.—The control wiring in a station must be absolutely reliable, easily repaired and flexible to changes. A high degree of segregation should be maintained, and exposed conduit is to be preferred to placing control conduits in floors or walls. In the very large plants separate control feeders should be supplied to all equipments and often duplicate feeders are installed. On many control circuits there is a great difference in the energy required on closing and on opening operations and each circuit may be divided into two parts—one part heavily fused and the other part lightly fused but coming from a common switch. A still further degree of reliability is obtained by using double-pole switches, double-control buses and either two batteries and one charging set or one battery and two charging sets.

The control circuits should be supplied from batteries and two or more sources of supply should always be available. The control wires should be installed so as to be protected from any faults occurring in power circuits and should be accessible for quick repairing and testing. It is usual to use 125 or 250 volts for the control circuits and most reliable operation is obtained when duplicate control circuits are installed to all equipment, including the low-tension auxiliaries and exciters. If possible, it is advisable to arrange a separate room or at least separate panels for the control wires, so that test clips, labels and fuses can be readily accessible and changes can be made without disturbing other station operations.

Protection and Control of Other Equipment.—Common practice uses 2,300-volt induction or synchronous motors for the larger auxiliary installations and a typical protective scheme for these motors is to use the same type of balanced protection as used on the generators without any overload or undervoltage protection, so that no transient disturbances will affect operation and the essential auxiliaries will stay on the line. Commonly, these motors are electrically controlled from push-button stations located near each motor, and in some cases duplicate remote control stations are located in main control rooms.

For smaller alternating-current motors a lower voltage is usually provided and carbon circuit breakers and knife switches serve for protective devices.

CHAPTER X

SWITCH HOUSE AND SWITCHBOARDS

The switch house of the modern central station is the center of the electrical system. It is the place where the energy is controlled, metered and delivered to outside circuits. It gives the station operators control of the main units, the exciters, the feeders, the oil breakers, the auxiliary and house services and, in some degree, control of the boiler room. It contains the metering and protective equipment and in addition the bus bars, the switches, the breakers, the main switchboards, the test devices and the reactors.

The design of a particular switch house and the choice of equipment to be installed depend on the type of plant, the capacity and voltage of the plant and the local conditions as to demands for service reliability and quality. A steam standby station for a hydro-electric system which feeds high-tension lines may have a very simple switch house with the generator leads positively connected to the low-tension side of the transformers located outside the station. Auxiliary and excitation control in this type of station will be minimized and localized at each unit. A hydro-electric plant feeding high-tension lines may also have a very simple interior switching arrangement based on the operation of generators and transformers as a unit. But when stations become very large or have many feeders or lines to supply, there is a necessity for an elaborate installation to handle the low-tension energy, and every precaution is used to secure an economical, safe and easily operated station.

The governing idea in designing a switch house is to secure reliable service and a direct route for the energy from the generator to the outgoing feeder. But these requirements are met with difficulty, for the switch house must contain a very large amount of equipment in order to give adequate energy control and sufficient operating data. Oil breakers, bus bars, disconnect switches, instrument transformers, switchboards, control wiring, meters and relays, reactors and test equipment must be used and installed.

A fire wall usually separates the switch house from the turbine room proper and the designer attempts to secure a minimum building cost by placing heavy equipment on the lower floors. It also is desirable to design the installation so that the failure of any piece of equipment or any circuit will not result in service

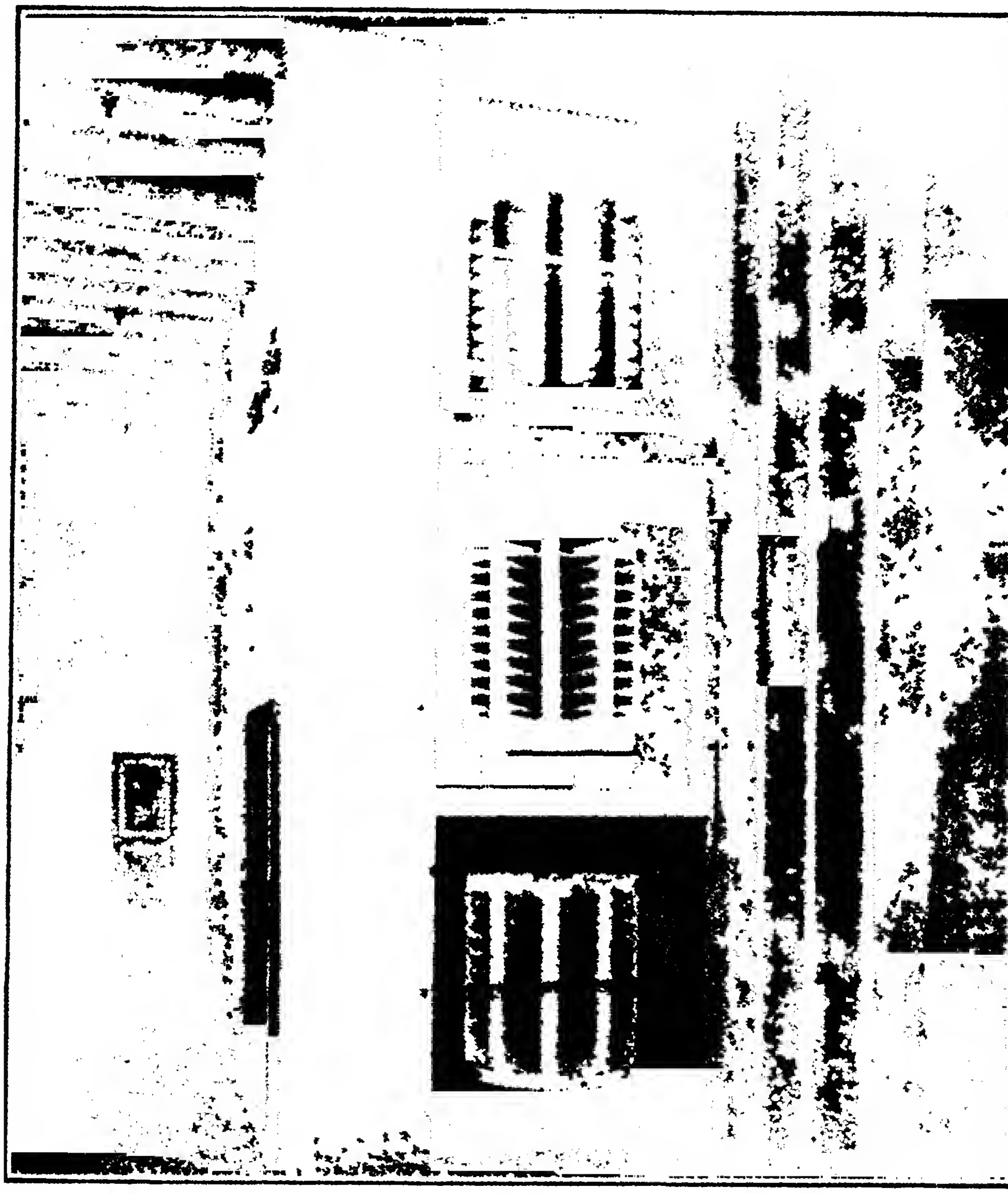

FIG. 149.—Reactor compartment arrangement where phases are grounded.

interruptions on a large scale or produce fires or hazards to the operating force.

Bus Arrangements.—Two general arrangements are used in the design of switch houses: (1) grouped phases and (2) isolated phases. In the commonly used grouped-phase arrangement it is customary to bring the generator leads through a three-phase oil breaker, disconnects and instrument transformers to three-phase bus bars placed horizontally or vertically in a bus gallery.

In the isolated-phase arrangement each phase of the generator is isolated with its corresponding switching and protective equipment in compartments separated by fire walls. Outgoing circuits are connected to the phase bus bars through reactors and are isolated from each other in the same manner. The phase isolation is used to reduce the chance of short circuits inside the station and either a horizontal or vertical separation may be used, depending on conditions. The vertical isolation

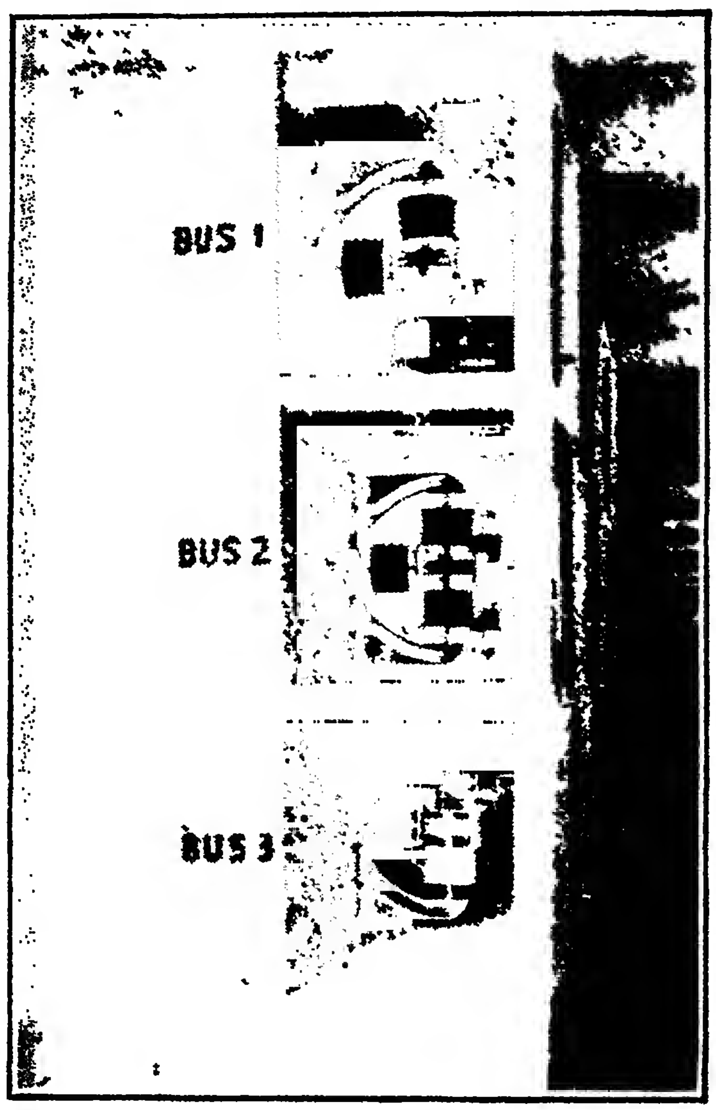

FIG. 150.—Arrangement for a 11,000-volt, three-phase bus using special insulators. Hartford Electric Light Company.

predominates in existing stations using phase isolation because it requires less ground area, less complexity in switching and less investment. The height required for vertical isolation is not objectionable since the boiler and turbine rooms also require high buildings.

With the vertical phase isolation it is possible to make several arrangements of the equipment. The operating room may be placed either at the top of the switch house or on the ground floor, and the heavy oil breakers also may be placed either on a lower or on an upper floor. The operating rods and bell cranks of oil breakers are located on the vertical walls of the mechanism

aisles and the cables pass from floor to floor through conduits placed in the walls and end in a cable room on the ground floor, or in the basement for stations supplying underground feeders.

Grouped-phase Arrangements.—Many different arrangements of bus and circuit breakers are used in stations, and local conditions govern decisions as to the best arrangement to use. Also the

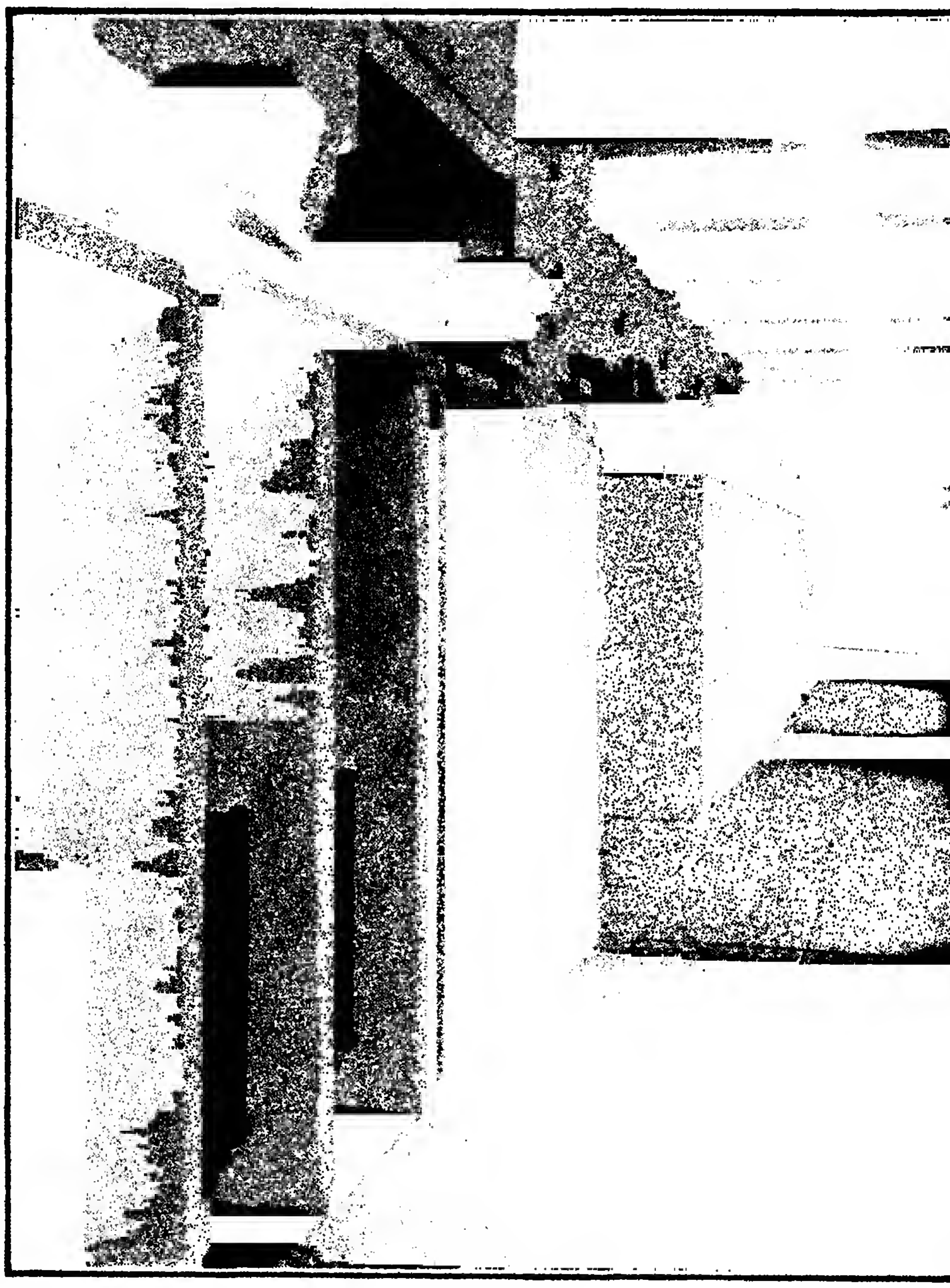

FIG. 151.—A group of 13,200-volt oil breaker cells in a switch house. The Philadelphia Electric Company.

magnitude of the loads to be handled, the number of feeders, the type of oil breakers used, the type of switchboard used and the general arrangements of other equipment influence the electrical layout. In general, it is necessary to provide a fireproof room for bus bars, oil breakers, instrument transformers and disconnect switches. Another room must be provided for the switchboard proper and still other rooms for the station battery,

outgoing feeders if the service is underground and testing equipment. Various other rooms are required, such as offices, storage rooms, shops and auxiliary switchboard rooms. And if the voltage is stepped up inside the station, the tranformers and high-tension bus bars, switches, etc., must be located in the switch house.

Bus-bar compartments are built of concrete or brick and rest upon the floor, generally with a vertical arrangement of the

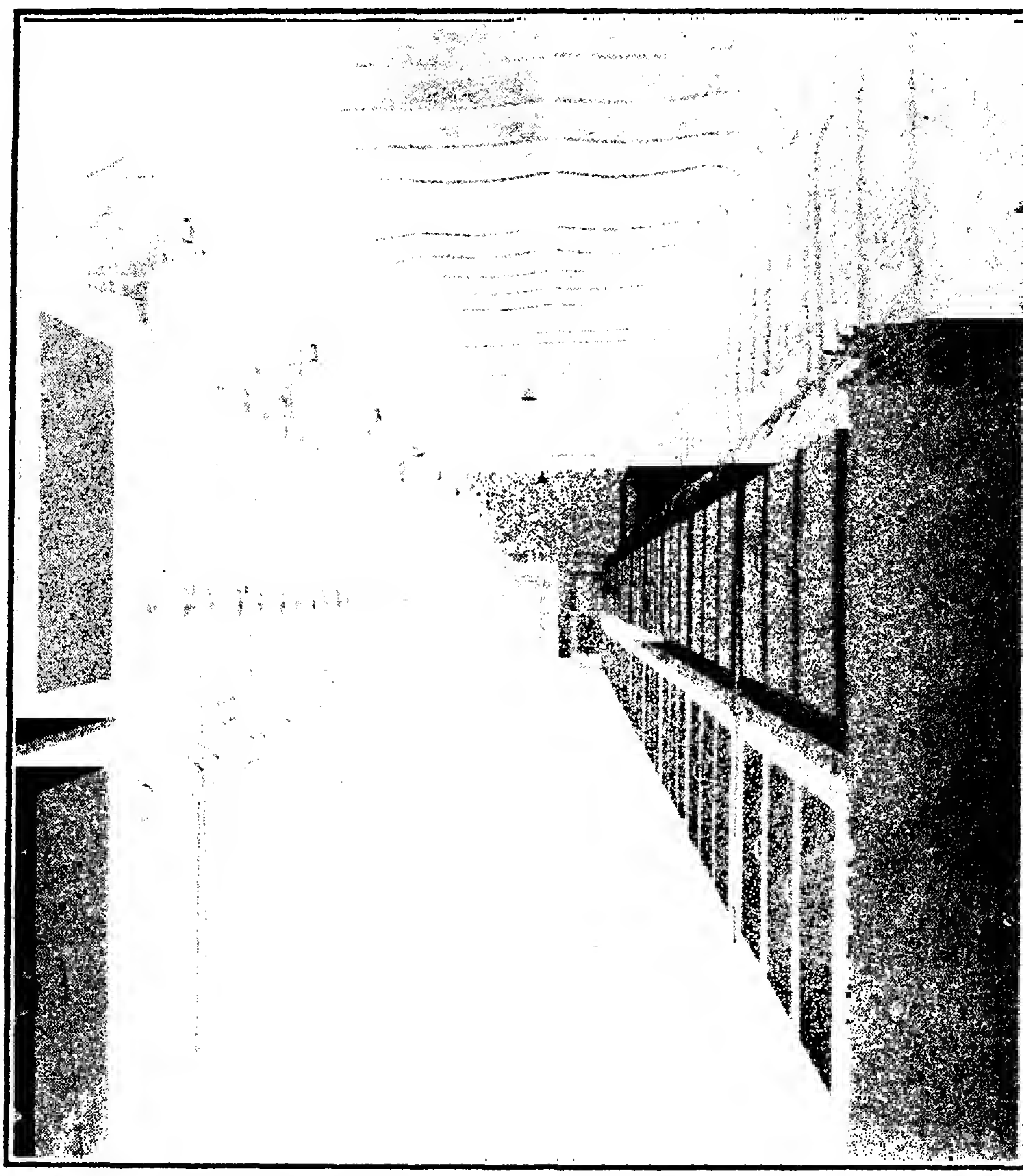

FIG. 152.—The switch room of the Oklahoma Power Company in its West Tulsa station.

buses. Oil breakers, disconnect switches and instrument tranformers are placed near the bus bars and utilize the bus compartment structure for support. The bus-bar compartments usually have walls about 4 in. thick and soapstone, slate, brick or concrete are used to make horizontal divisions. Doors are placed on the compartments and are equipped with locks or other

safeguards to insure that all parts in the compartment are dead when an operator opens a door. Views of typical arrangements are shown. H. A. Travers[1] has shown other installations.

Standard bus-bar ratings have been adopted by the Electric Power Club, based on 40°C. ambient temperature, as indicated in the curves of Fig. 161. These curves are to be used for currents not exceeding 3,000 amp. The spacing between laminations is ¼ in., each lamination being ¼ in. thick. A spacing of 8 in. is left between phases. A minimum contact pressure of 250 lb. per square inch is specified for bolted or clamped connections and a maximum operating temperature of 70°C. is to be used in the design of the bus bars and their connections for the general case.

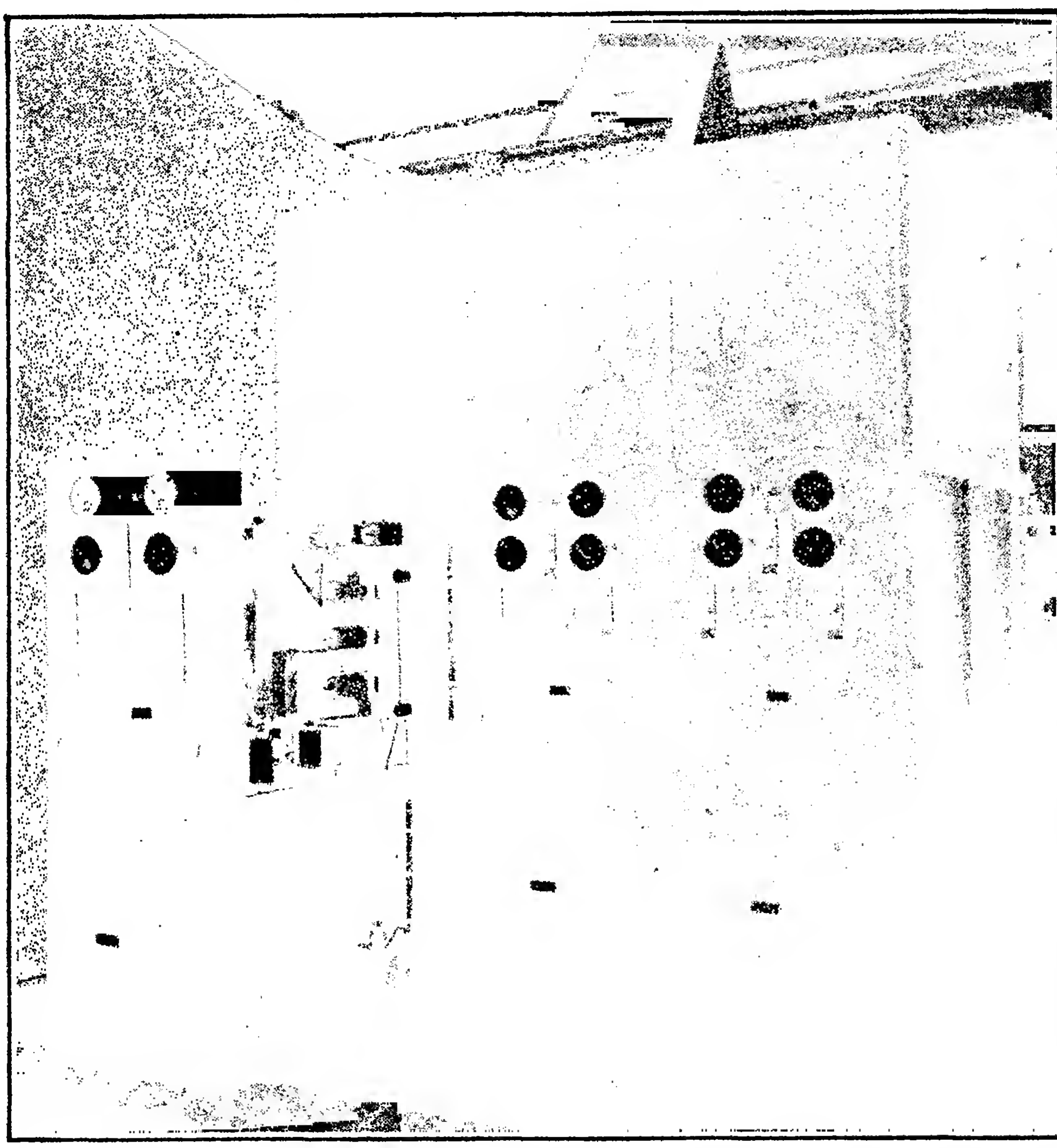

Fig. 153.—A 15,000-volt, safety, enclosed, removable-truck type of switchboard, General Electric Company.

[1] "Switchboards and Switchgear for A. C. Power Stations," Publication Department, Westinghouse Electric & Manufacturing Co.

Enclosed or Dead-front Installations.—A new and very popular arrangement for bus bars and breakers is illustrated in Fig. 153. This is a steel compartment with a removable truck containing the oil breaker and instruments. It costs about the same as the older type of installation and has many advantages as regards safety, compactness and ease of repair. It combines in

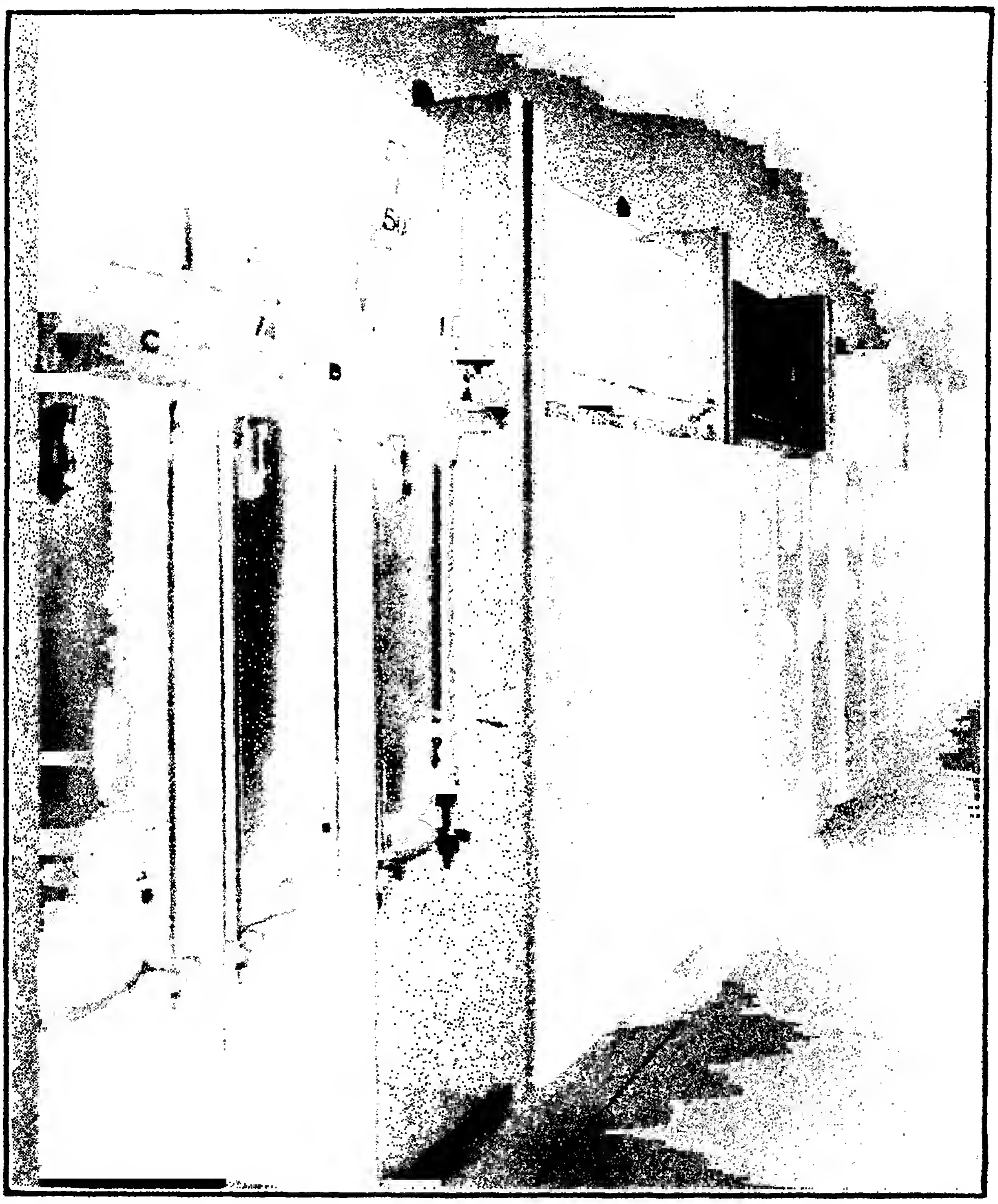

FIG. 154.—Bus selector 13,000-volt switch cells as installed for the Philadelphia Electric Company. Doors are removed from one switch.

one unit the switchboard, oil breaker and meters and is particularly well adapted to unit installations where no generator bus is used and to feeder service.

Isolated-phase Switch Houses.—The general scheme for isolated phases in switch houses was devised by B. G. Jamison, of the Commonwealth Edison Company, and has been applied

to several large stations. Experience indicates that it prevents interphase short circuits, requires no greater space dimensions than the group-phase arrangement and costs no more. The scheme should be arranged so that energy-limiting reactors are located on each phase at such points that there is no proximity of

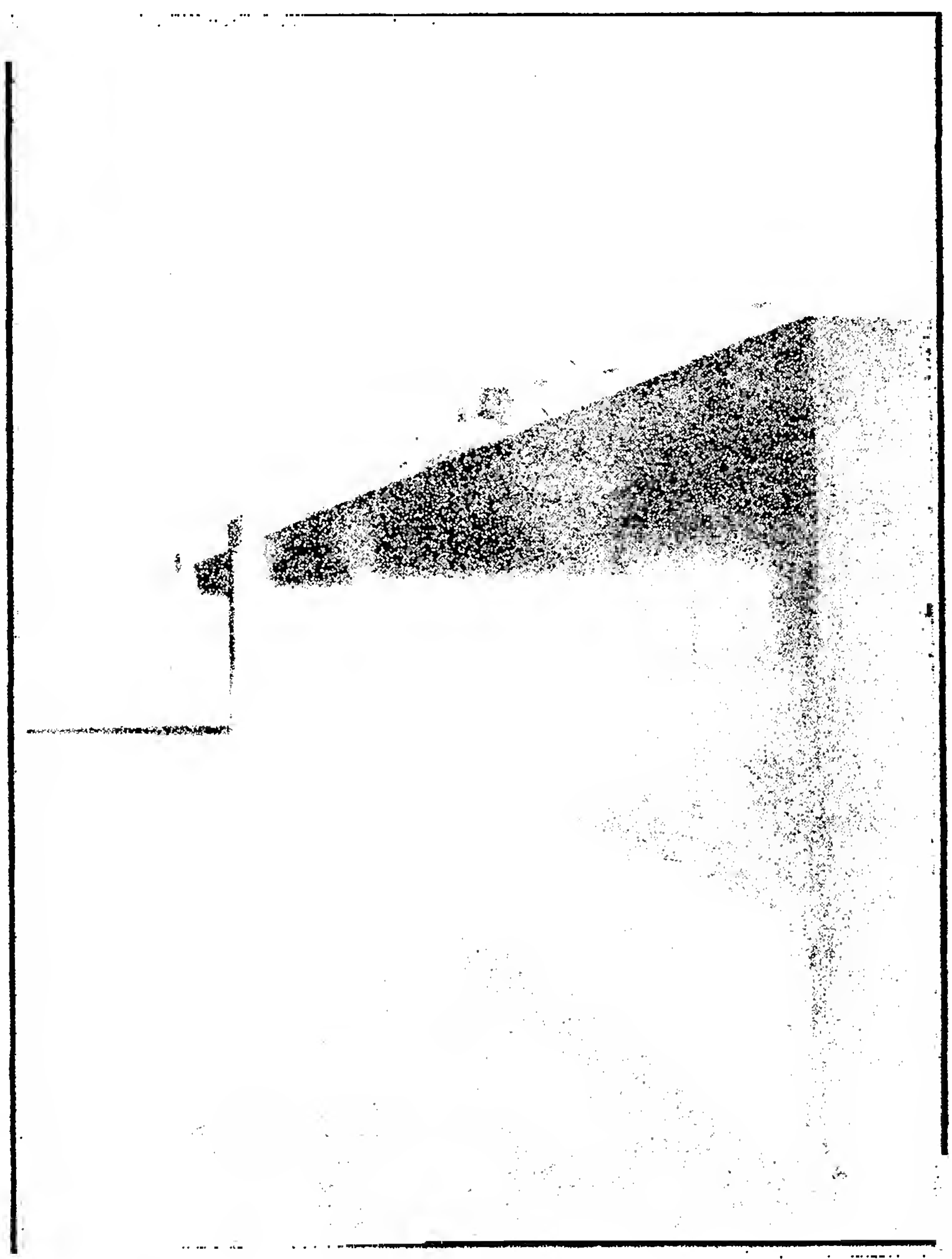

FIG. 155.—11,000-volt oil breakers and disconnect switch compartments used by the Hartford Electric Light Company.

phases except beyond energy-limiting reactors. It is applicable to stations requiring simple as well as complicated switching requirements and has proved very satisfactory in service. Figure 162 shows the arrangement used in the Calumet station of the Commonwealth Edison Company in Chicago. In Figs. 156 and 157 are shown single-line diagrams of circuits and plans and

sections of isolated-phase stations as proposed by P. M. Currier and W. T. O'Connell.[1] Other stations are shown.

In using isolated-phase arrangements, reinforced-concrete buildings are preferred to structural-steel buildings because less eddy currents and hysteresis losses result from the induction resulting from the single-phase conductors. All loops must be carefully avoided on this account, and careful grounding and bonding of all metal structures are necessary precautions. In some cases copper hands should be placed around steel structures forming vertical loops at right angles to the bus bars.

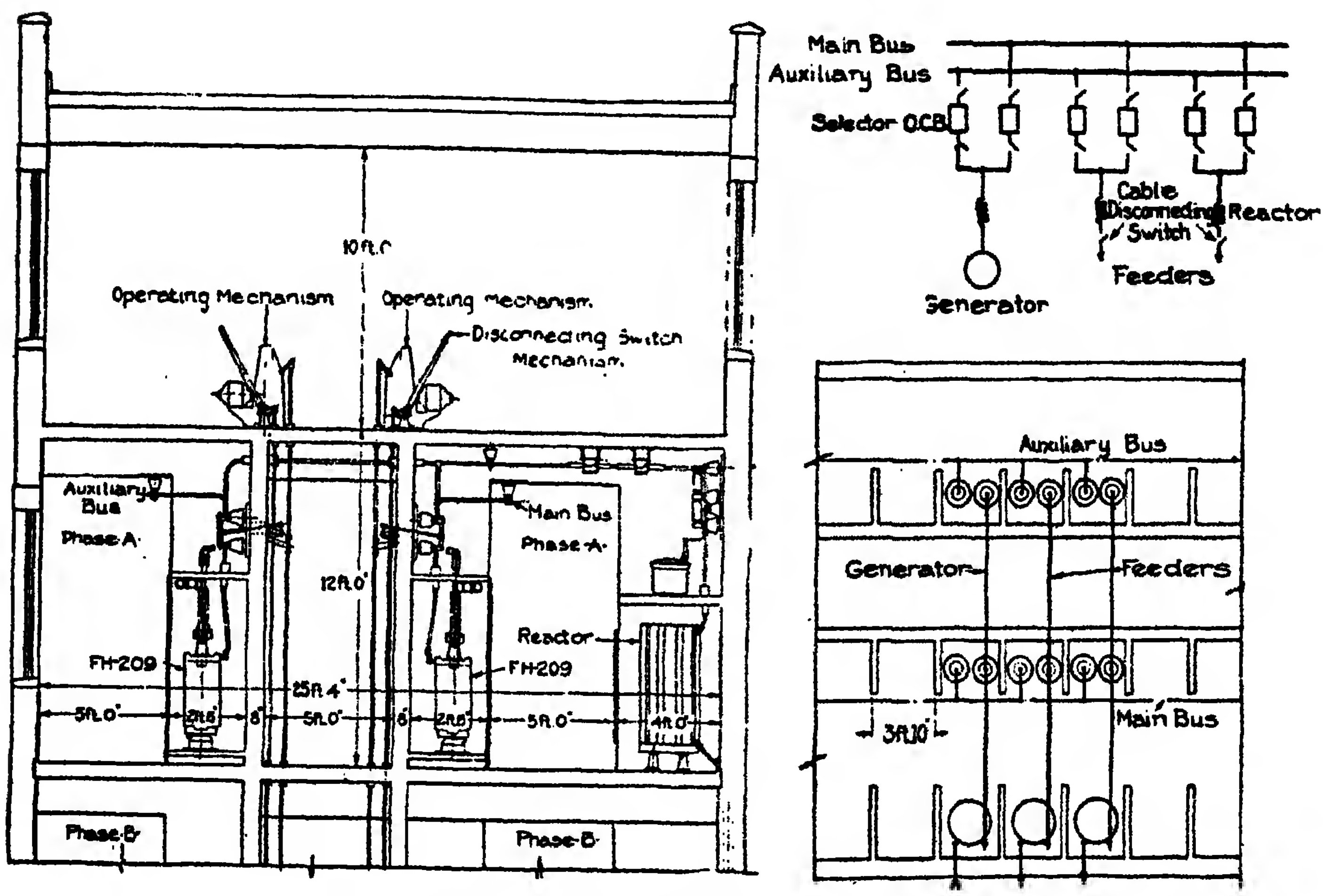

FIG. 156.—Single-line diagram of connections and corresponding switch-house arrangements.

The complete isolation involves the use of separate rooms and fire walls for main buses, oil breakers and auxiliary buses of the same phase and in some cases reactors are also isolated. The operating mechanism and disconnect switches are also isolated from the breaker compartments. Each group of equipment is also separated by necessary fire walls in a transverse direction. In general, the control room is best located adjacent to the mechanism floor in order to reduce the lengths of control runs, but the arrangements sometimes call for the location of the control room above the mechanism rooms or over the auxiliary and house-

[1] "Isolated Phase Arrangement of Switching Equipment," *General Electric Review*, June, 1923.

service room in order to obtain space for conduits and a highly desirable control circuit test and terminal room beneath the main control room. Connections in the main circuits are made with copper bars or pipes and these connections must be heavy and strong and without abrupt bends. In some cases the bars or pipes are insulated with micarta, which increases their strength and adds to the safety of operators.

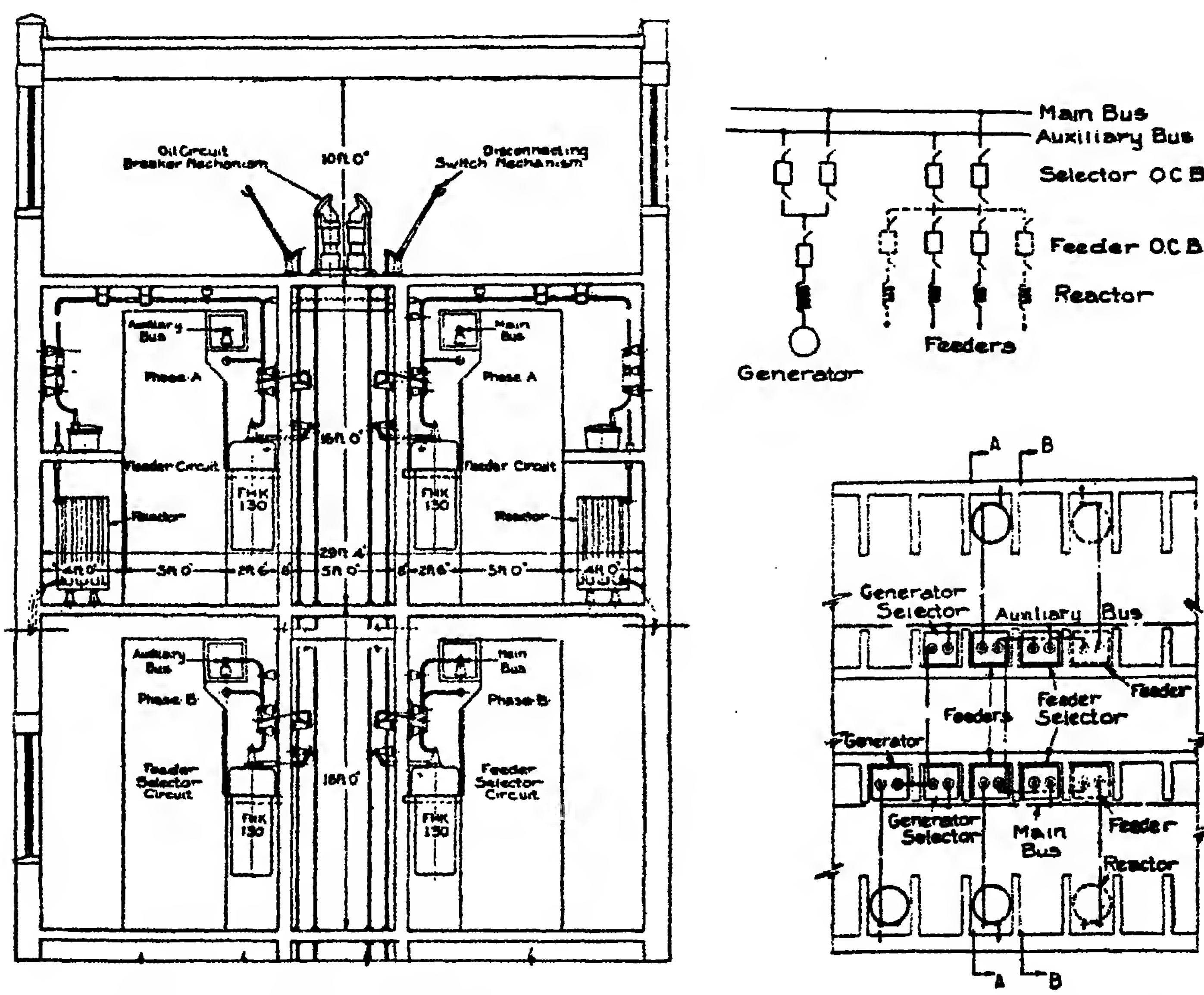

FIG. 157.—A one-line diagram of a complicated but very common type of circuit. The feeders have reactors and are grouped with two selector switches for each group of two or more feeders. Each generator circuit has a main oil circuit breaker, two selector oil circuit breakers and a reactor. Thus there are two breakers in series in every circuit. A section of a vertical isolated-phase switch house corresponding to this arrangement of equipment is shown at left and a plan at the right.

Disconnect switches are usually gang operated by hand or motor and interlocked with the breakers so that they cannot be operated when the breakers are closed. Three potential transformers for metering can be connected Y on primary and secondary, if there is only one system ground, but if more than one system ground is used, then, if a ground is available, two transformers can be connected from bus to ground or, if no ground is available, three transformers in Y with variable impedances can

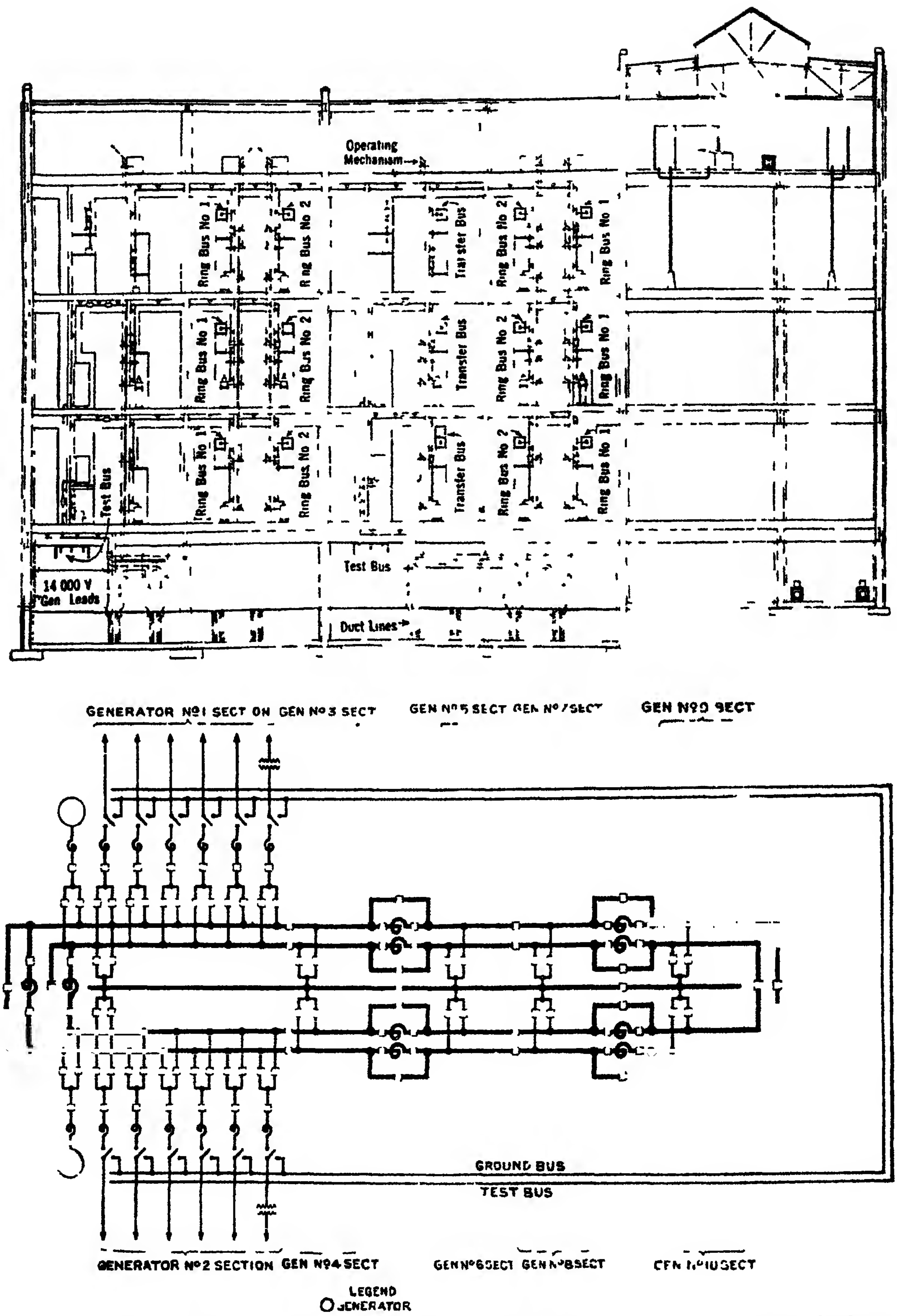

FIG. 158.—Main connections and cross-section of the isolated-phase switch house in Edgar station of the Edison Electric Illuminating Company of Boston.

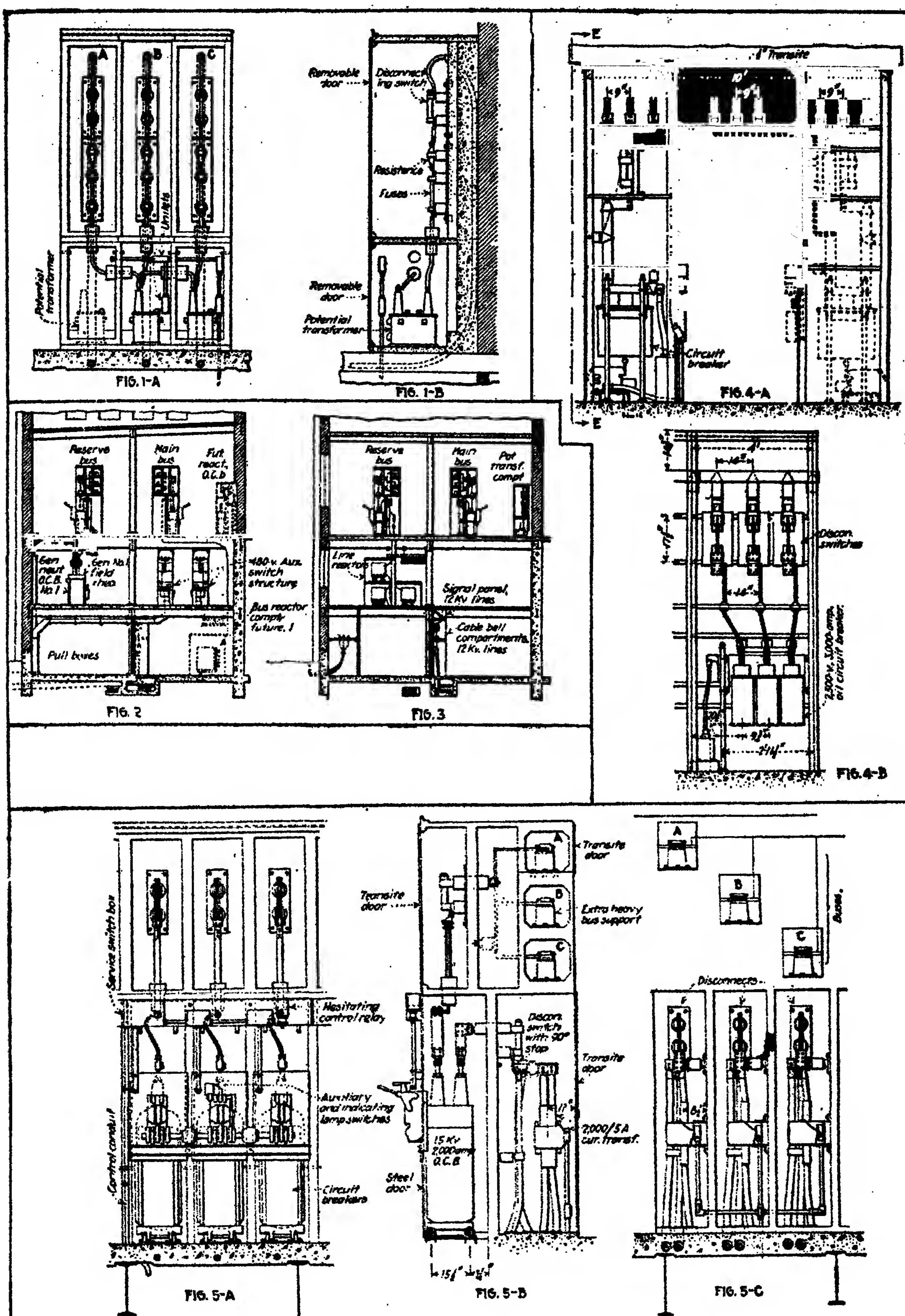

FIG. 159.—Design details of switch house in Waukeegan station of the Public Service Company of Northern Illinois. Figs. 1*A* and 1*B*, elevation and section of potential transformer compartments; Figs. 2 and 3, bus and line sections through switch house; Figs. 4*A* and 4*B*, section and elevation of auxiliary service bus mounting; Figs. 5*A*, 5*B* and 5*C*, east elevation section and west elevation of main bus.

be used to obtain an artificial system neutral. Bushing- or bar-type current transformers can be used as desired. Ground and test bus locations and reactor arrangements depend on local conditions and building layouts.

Typical layouts for vertical-phase isolation are found in the Calumet station of the Commonwealth Edison Company, in the

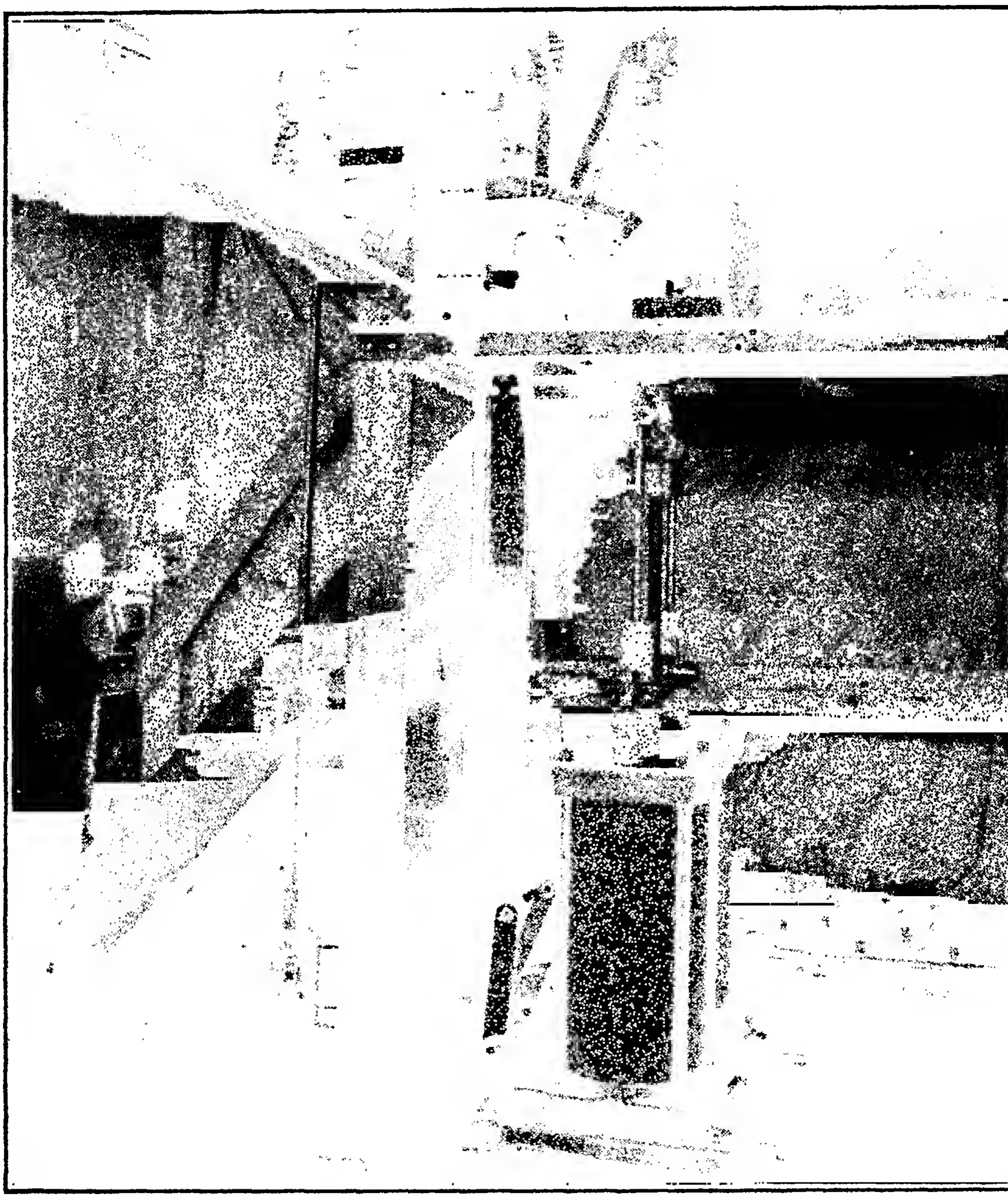

Fig. 160.—Oil circuit breaker and disconnect switch arrangement for isolated-phase operation, Commonwealth Edison Company.

Cahokia station of the Union Electric Light and Power Company of St. Louis and in the Avon station of the Cleveland Electric Illuminating Company. (See Figs. 162, 163 and 177.)

Switchboards.—Switchboards in power plants serve to localize control and metering and they take many forms. In general, there are three types: (1) auxiliary-service boards, (2) main switchboards, (3) metering and relay switchboards.

The auxiliary-service switchboards are of the panel or deadfront-unit enclosed types and may be located where desired. In a unit system there will be service boards in the boiler room and at each major auxiliary. In other stations the main auxiliary-service board will be located in a separate room in the switch house and in still other stations combinations occur. In general, the principle should be followed that a minimum amount of wiring and a minimum number of attendants should govern the layout, but sight must not be lost at all times of the demand for service reliability. A first, second and even third line of defense must be provided for control of essential auxiliaries and this may involve both local and centralized control boards. Also it is essential that metering be sufficient to obtain data for maintaining the efficiency of the plant.

A general trend is to make the boiler-room auxiliary board self-contained with signals to the main electrical operating room. In the turbine room the exciter boards are located at each unit for the most economical installation. Turbine-room auxiliary control boards are placed in a balcony or in a separate room in the switch house with some degree of duplicate and interlocking control to the main operating room.

The main switchboards are placed in an operating room and, in general, the meter and protective panels for the main circuits are placed in this same room. So many differences in

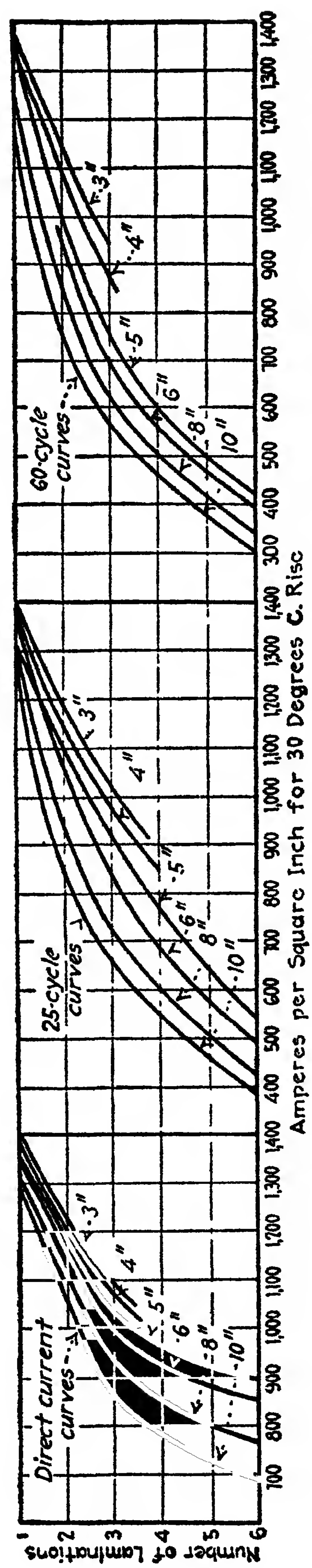

FIG. 161.—Current-carrying capacity of the usual sizes of copper buses based on 40°C. ambient temperature, Electric Power Club.

load, service, and design conditions are found that each plant becomes a special detailed study for the location of switchboards and the equipment to be used on each board.

Any switchboard should be located, installed and wired so as to get the simplest layout consistent with the necessity to

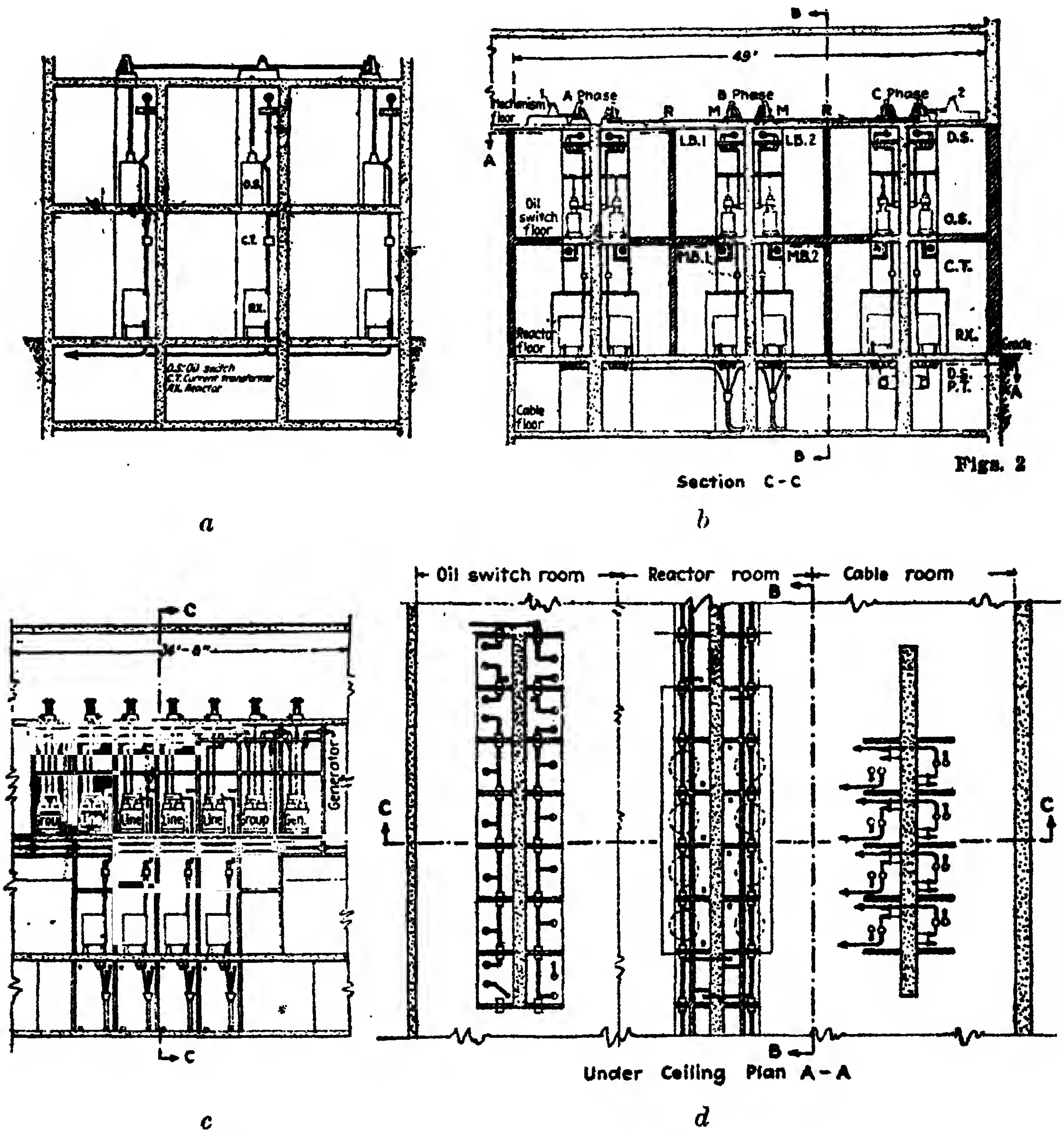

FIG. 162.—Isolated-phase switch-house arrangement in Calumet station of the Commonwealth Edison Company, Chicago. *a*. Simplified layout for basic design. *b*. and *c*. Extreme spacing and truck-type oil breakers were used. Similar apparatus is placed on one floor. *d*. Under ceiling plan for the three floors of the switch house as shown in *b* and *c*.

localize trouble, maintain service and afford efficient operation under normal conditions. The first cost is a minor item as compared to the service the switchboard is designed to render.

The modern switchboard may contain any or all of the following types of equipment:

1. Indicating.—This includes meters, lamps, synchroscopes, and relays.

2. Control.—This includes all positive remote-control devices to operate oil breakers, governors, auxiliaries, etc.

3. Protective.—This includes relays and all apparatus protective devices.

4. Signal.—This includes annunciator, telephone, lamp and other signals to various parts of a plant.

5. Metering.—This includes all graphic recording and integrating meters.

The selection of this equipment and its installation requires care and involves at best an elaborate layout for wiring circuits. Yet each small meter or control wire must be as reliable as any other circuit in the station, if efficient service is to be rendered under all circumstances. The ideal switchboard should bring to a focus or to the attention of one man:

1. All indicating, control and signal devices necessary for him to ascertain the instantaneous condition of the essential equipment in the power house and to locate trouble and isolate it with a minimum delay.

2. All equipment necessary to determine the operating efficiency of a station and sufficient control of equipment to maintain this efficiency under all service conditions.

It is impossible to attain this ideal in a big modern station, and at best several operators must be used and several subswitchboards and their attendants must be relied upon to act under orders of a chief operator or load dispatcher. Also it is necessary to do a great deal of efficiency work after the data are obtained. In other words, after a station operates poorly, data should show why and conditions can then be remedied, but it is difficult to keep all parts of a station operating efficiently at the time data are made.

Switchboard Designs.—A switchboard takes many forms but, in general, there are four classes:

1. Vertical-panel type.
2. Bench-board type.
3. Pedestal type.
4. Dead-front safety type.

The vertical-panel type usually is made up of three slate sections and allocates to each panel a machine or a division of a station. They are used very commonly for auxiliary-service

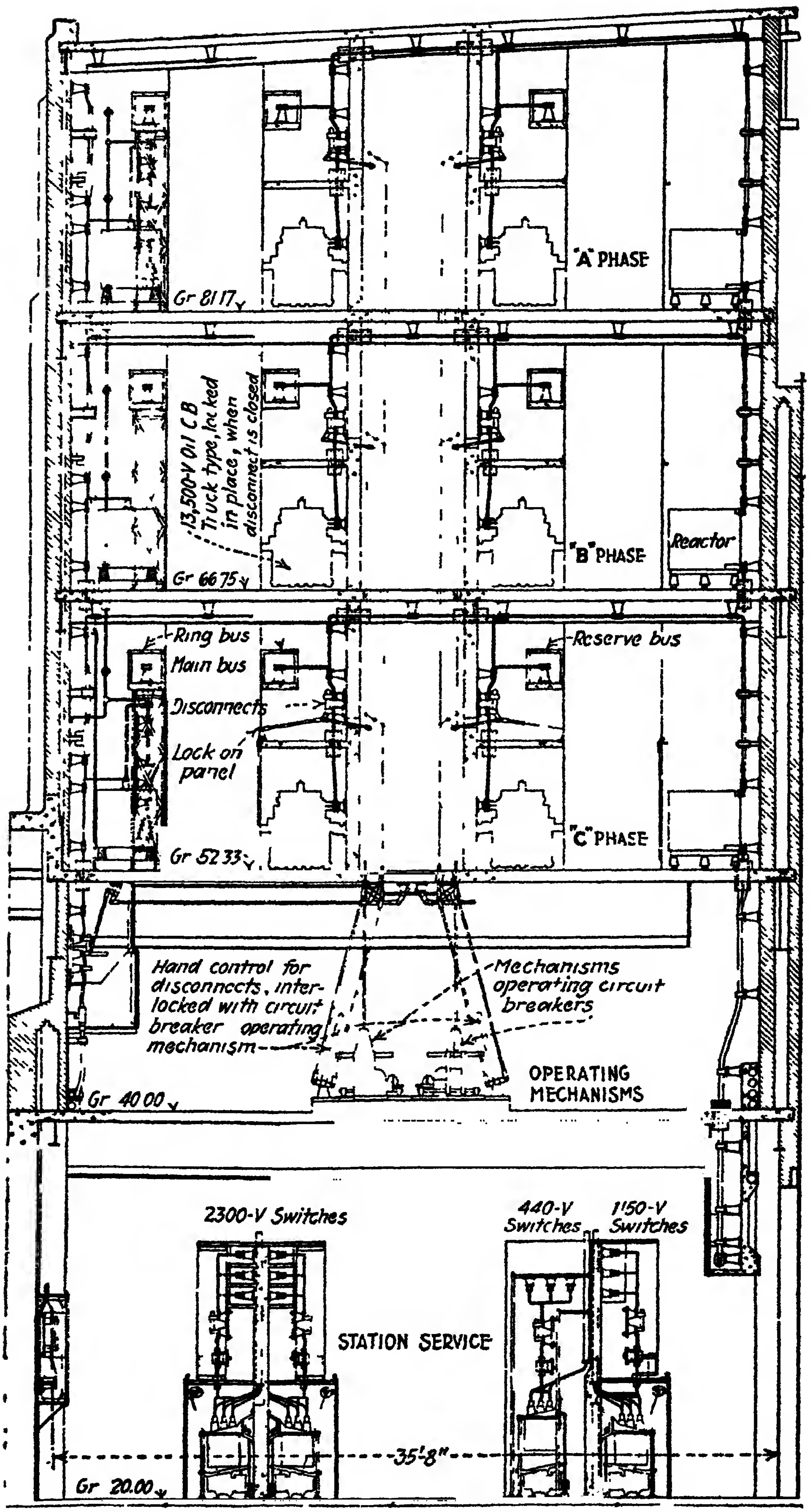
"A" PHASE
Gr 81 17
13,500-V Oil C B
Truck type, locked
in place, when
disconnect is closed
"B" PHASE
Reactor
Gr 66 75
Ring bus
Main bus
Disconnects
Lock on
panel
Reserve bus
"C" PHASE
Gr 52 33
Hand control for
disconnects, inter-
locked with circuit
breaker operating
mechanism
Mechanisms
operating circuit
breakers
OPERATING
MECHANISMS
Gr 40 00
2300-V Switches
440-V
Switches
1150-V
Switches
STATION SERVICE
35'-8"
Gr 20.00

Fig. 163.

switchboards and in low-voltage stations for generator and feeder service. The dead-front safety enclosed-truck type board is used for the same service and has become a keen competitor in recent years.

The bench-board type of switchboard flourishes in very large stations and as usually designed it contains several panels and a miniature layout of the main station wiring. Signal lamps and control knobs are located on the miniature wiring layout and

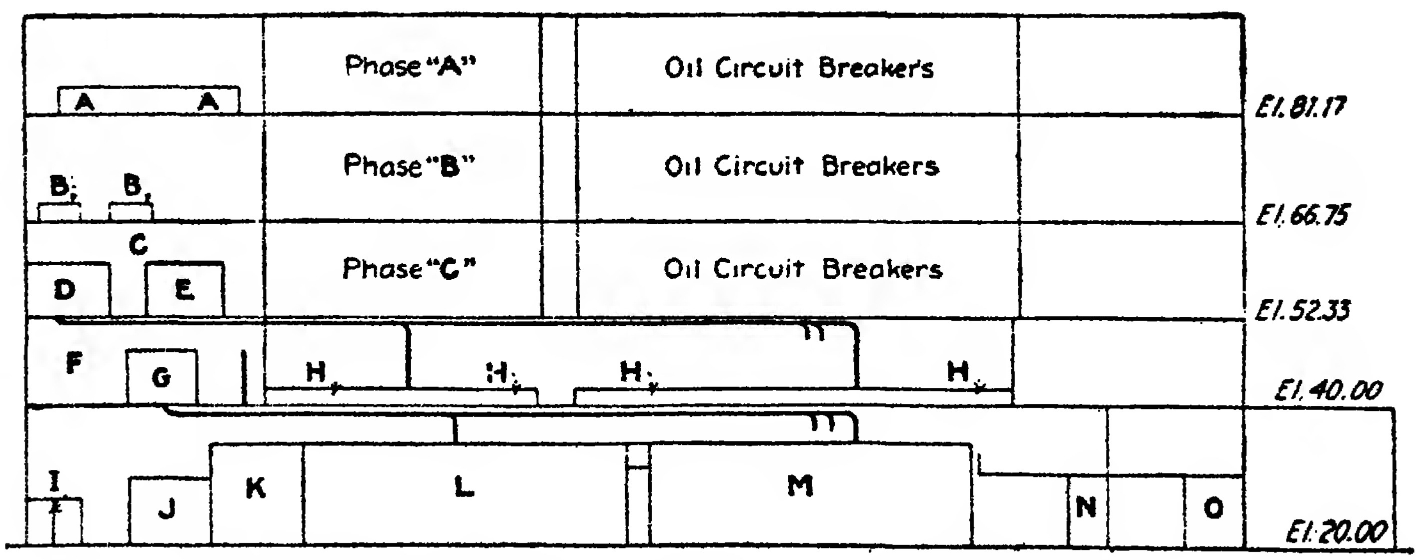

FIG. 164.—Diagrammatic cross-section of bus and switching structures of the Cahokia station.

The phase chambers for each main unit are separated by concrete walls and intervening floors; the circuit breaker and disconnect switch mechanism are on a floor below the lowest phase floor; the switchboard control rooms for 13,800-volt equipment and auxiliary circuits are close to the main operating floors of the station, which are at grades +40 and +20; the auxiliary circuit breakers are on the lowest operating floor convenient to the auxiliaries.

A. Storage batteries.
B. Motor generator.
C. Main generator and feeder control room.
D. Feeder board.
E. Generator board.
F. Water supervisor's room.
H. Oil circuit-breaker mechanisms.
I. Generator neutral ground resistor.
J. Compensators.
K. Reactors.
L. 2,300-volt station service.
M. Oil circuit-breaker structure.
N. Compensators.
R. Reactors.

meters are placed on the vertical part of the board. This type of board is very popular and is easy to operate, but as the complexity of control circuits and the number of meters increase it becomes of less advantage because of the difficulty in installing wiring, difficulty in testing and maintaining wiring and difficulty of finding space for all meter, control and signal devices. Thus there is a tendency toward the use of subdivided switchboards in

FIG. 163.—Vertical-phase isolation in the Cahokia station of the Union Electric Light and Power Company, St. Louis.

This arrangement permitted a narrow foundation (necessitated by foundation difficulties), brought weights close to the foundation, minimized the superstructure cost, reduced the length of control wiring and brought the control rooms in close proximity to the operating floors. The switch mechanism is not exposed to fumes or flames from equipment troubles. It is claimed the simplicity of arrangement minimized construction and installation problems, facilitates inspection and test, and affords less cramped quarters than when grouped phases are used. Each section of each bus is in a separate chamber that can be ventilated by forced-draft fan.

large stations in the form of two parallel rows of vertical panels or a combination of a bench board and a vertical-panel board.

The pedestal-type board as first used had a cluster of meters at the top and a few control devices on the pedestal. It has

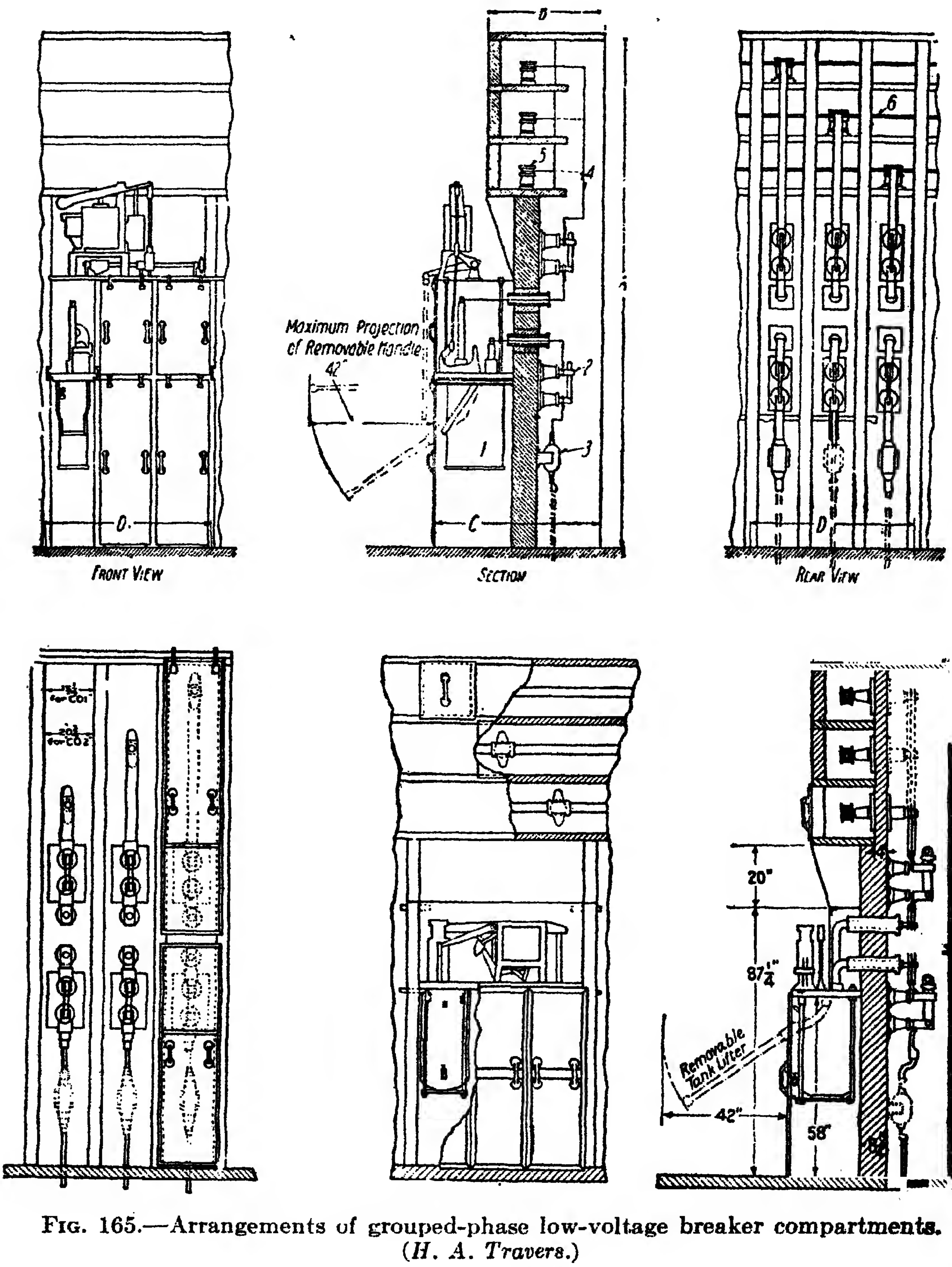

FIG. 165.—Arrangements of grouped-phase low-voltage breaker compartments. (*H. A. Travers.*)

undergone great modifications and is little used because of its inadequacy for all meters, controls and miniature circuits now required in large installations.

Panels in switchboards are ordinarily made of slate and are supported on angle-iron or pipe frameworks. The wiring is of fireproof character and is of the type used for remote control. In other words, it consists of miniature circuits, fuses, switching and connecting devices and yet demands an installation that will be reliable and easily maintained. In the layout of boards, the panels are located in a semi-circle or sector of a circle with a main

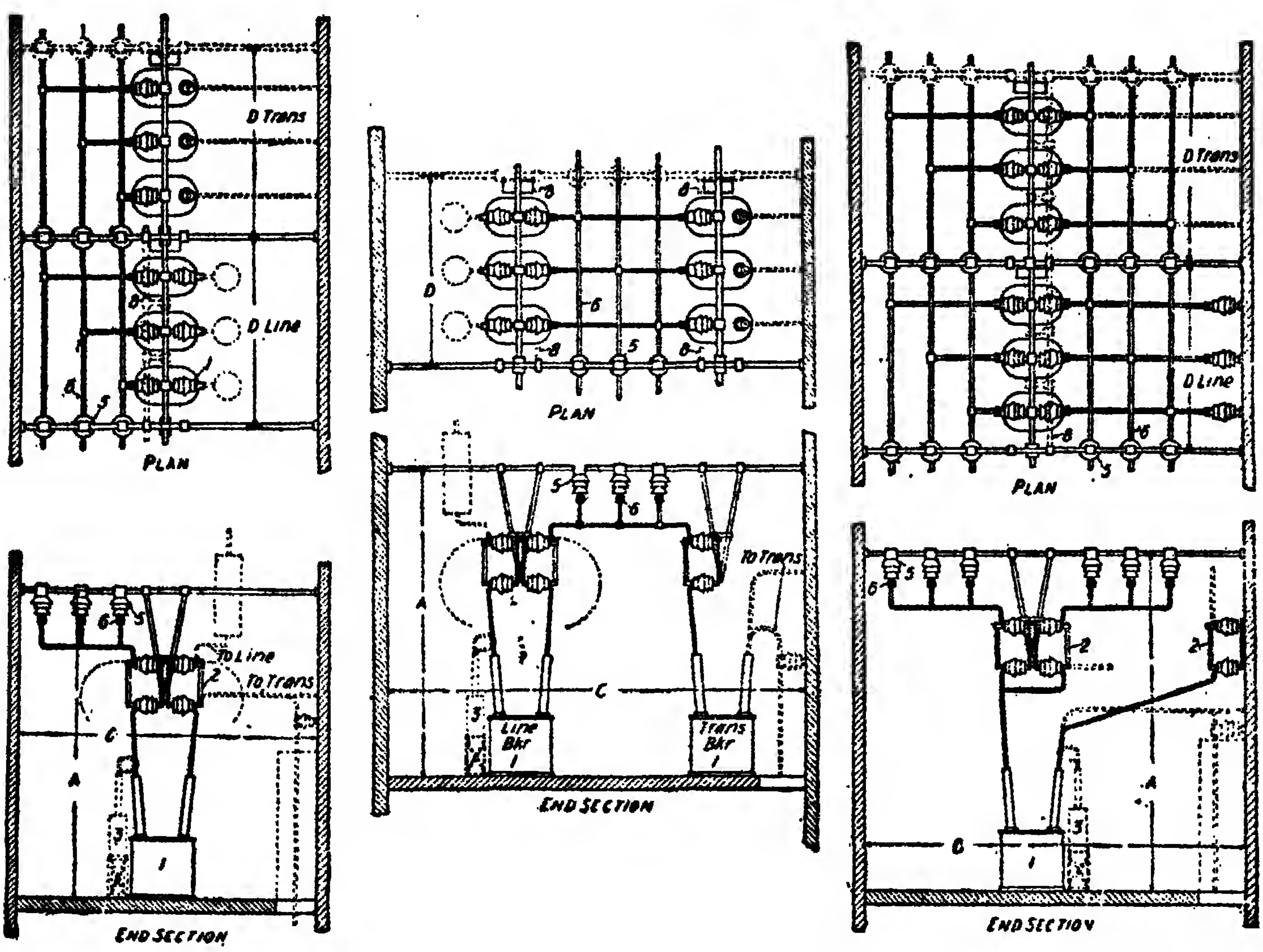

FIG. 166.—Various arrangements of floor-mounting circuit breakers for high-tension structures of 22,000 volts and upward. *a* shows an arrangement for a one-breaker single-bus system with disconnecting switches on either side of the breaker if desired, when a long rectangular space is available. *b* shows an arrangement for a one-breaker single-bus layout where a wider space is available and thereby cuts down the total length of the high-tension room by placing the breakers in two rows. *c* shows an arrangement for a one-breaker double-bus system.

control desk in the center. This gives greater visibility to operators and reduces the space requirements. In some cases two switchboards will be installed in the same room, having operating aisles between them. In these cases integrating and recording meters and protective equipment are usually located on the vertical boards invisible from the main control desk and essential signal and indicating equipment on the bench boards. Types of switchboards are shown in Figs. 169 to 172.

Metering Equipment.—Metering equipment should be selected for the given plant on the basis of:

1. A minimum number of meters to secure reliable operation under all conditions without sacrificing any essential accuracy in economic operation.

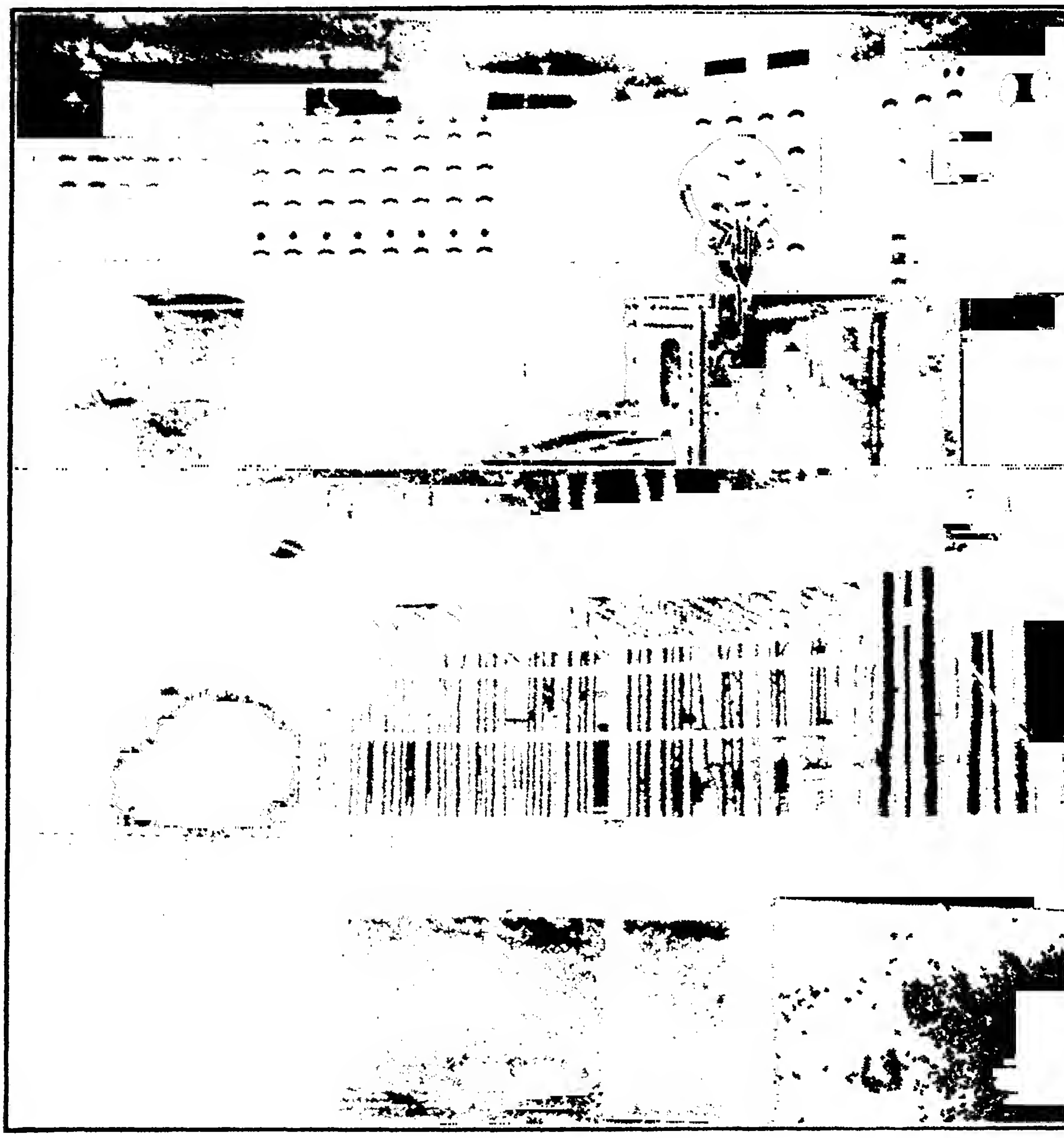

FIG. 167.—A good arrangement for a large power station uses a control wire room located under the main switchboard. The Philadelphia Electric Company.

2. Suitability for the type of switchboard attendant used in the plant.

3. Economy in relation to switchboard cost in comparison with other items of plant cost. Special instruments or delicate instruments are only warranted under particular conditions.

The following classification of requirements conforms to usual practices:

a. Exciter Panel.—An ammeter is required to show the heating of the exciter, the division of load between exciters or the load on each feeder from the exciter bus. A voltmeter is needed to show the operating voltage conditions and to safeguard insulation, to obtain parallel operation and to be used as a ground detector in certain cases. A curve-drawing ammeter gives a permanent record of running condition, so that a record is available if acci-

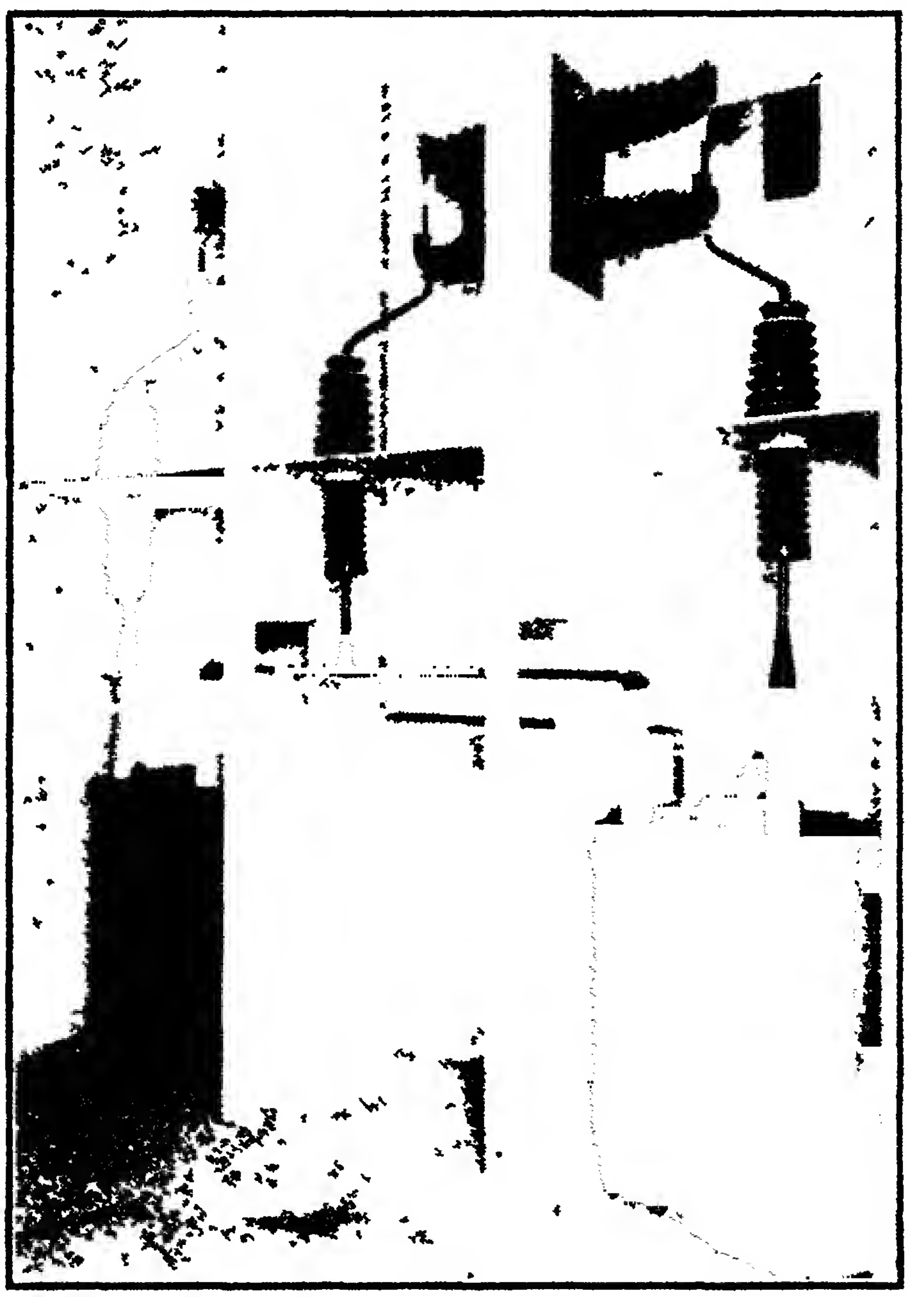

Fig. 168.—Potential transformer compartments and connections.

dents occur. Meters can be used sometimes to integrate excitation energy for use in station economics.

b. Main-unit Panel.—An alternating-current ammeter in each phase gives an indication of balance, phase heating and division of load in parallel machine operation. It also affords power-factor adjustments in parallel operation. An alternating-current voltmeter gives an indication of operating voltages and safeguards service potential and insulation. It is needed for paralleling, and can be used with compensators to determine the voltage at any point on a line.

A field ammeter gives an indication of excitation conditions, the heating of main-unit fields, proper power-factor adjustments and can be used for test purposes.

Indicating wattmeters give the actual power delivered, the division of load in parallel operation, check other meters on load-curve data, indicate power reversals and aid in determining power factor. A power-factor meter shows the power-factor conditions and checks excitation in parallel operation; it also serves to check power-factor determination from other data.

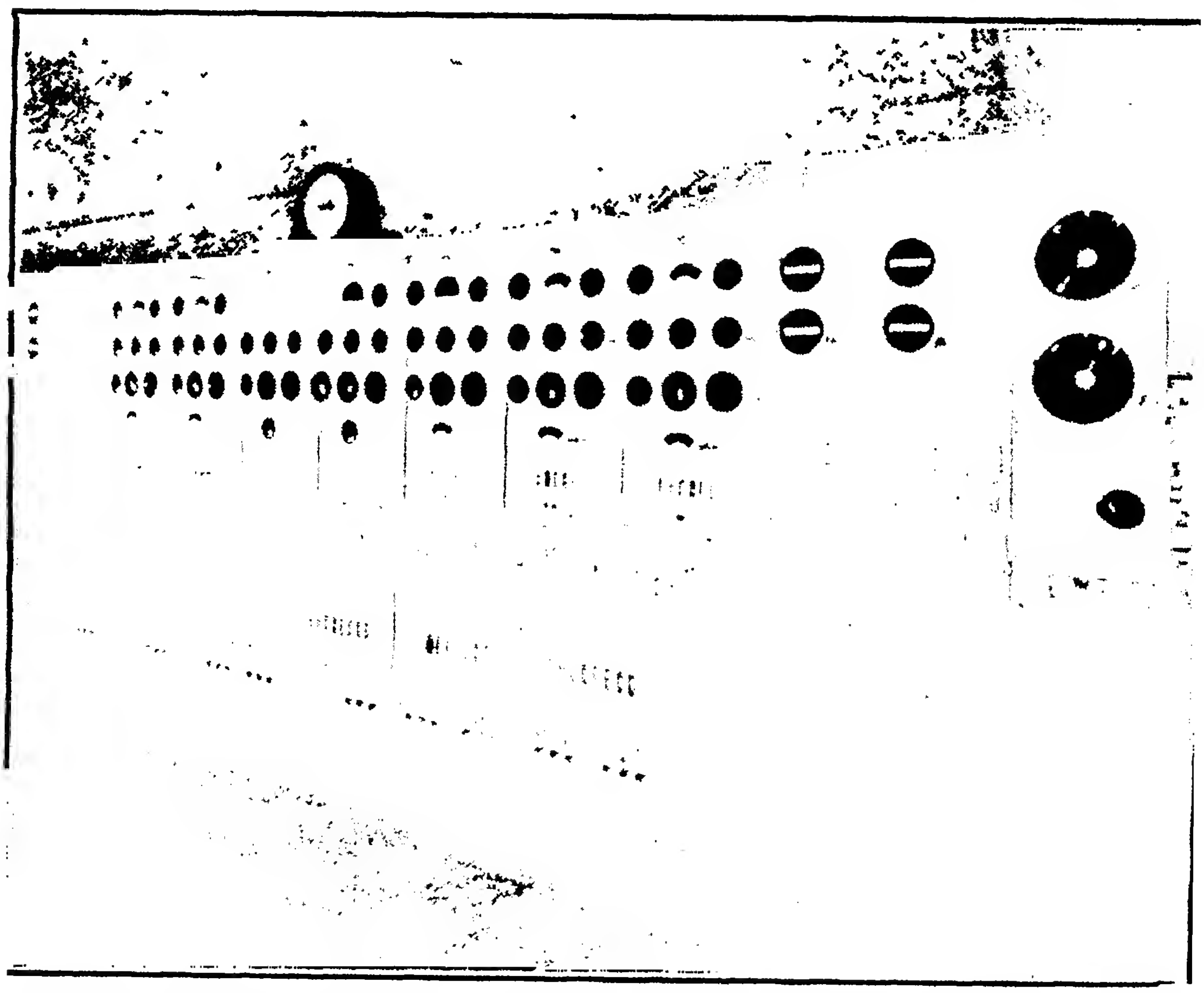

FIG. 169.—Generator and frequency changer control boards in Hell Gate station of the United Electric Light and Power Company, New York.

A reactive volt-ampere meter gives directly the wattless power and checks the data for determining power factor. It is a better indicator on small changes of power factor than a power-factor meter and gives a quantitative reading as compared to the per cent reading of a power-factor meter.

A frequency indicator helps maintain constant service frequency and shows the point for economic operation. It also helps in synchronizing. Synchronizing lamps and synchronoscopes of some type are needed in paralleling machines. The

recording type gives a record and check on station operation in the event careless operators cause trouble.

An electro-static ground detector gives a continuous indication as to grounds and can be checked by ground lamps. It is better than lamps in that it indicates the magnitude and phase of a ground. Its liability to error and to give false indications has resulted in use of lamps also as a check.

Temperature indicators and recorders insure knowledge of operating conditions, prevent trouble and give a record of machine internal conditions, Curve-drawing meters give a

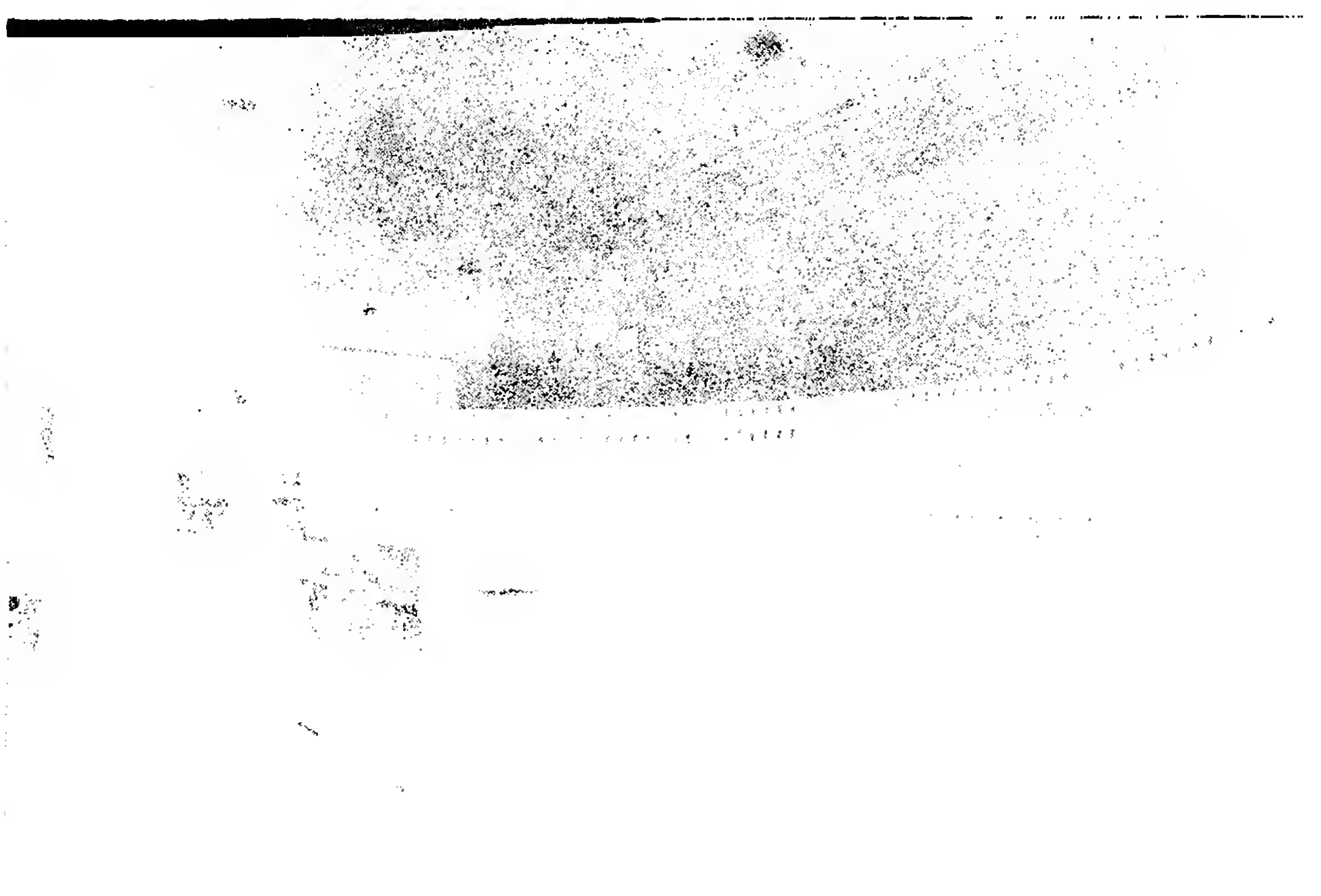

FIG. 170.—Feeder control board in Hell Gate station.

permanent and visual record of station performance and check other data. They also serve to indicate conditions at the time trouble occurs.

Integrating and totalizing meters save time and check other data and are useful for obtaining data by which the economic performance of a station can be determined. Special meters, such as weather meters, barometers, etc., are aids in predetermining service conditions so as to adjust the loads on apparatus.

The use of three ammeters is preferred on three-phase circuits to using an ammeter switch. The number of instruments or relays on a given set of instrument transformers depends on the total load and the accuracy desired and to some extent upon the

service. A general rule is never to exceed the voltage or current rating of the instrument transformers. A wattmeter should never be connected with transformers used for differential protection, reverse-energy relays, a compensated voltmeter or a line-drop compensator.

The same transformers can be used for instruments and potential coils of relays, low-voltage releases, etc., so long as ratings are not exceeded. The secondary circuit and transformer and

FIG. 171.—Relay board and wiring on rear of instrument panels. The Philadelphia Electric Company.

instrument frames should always be grounded for safety and for removing electrostatic charges.

The operator should observe a minimum number of indicating instruments, as the tendency is for him not to see many meters. In the event of trouble the operator should be able to touch immediately the control that removes or isolates the trouble. In the low-tension parallel-bus system, there are many meters and the operator cannot determine the source of trouble immediately —he either goes out the door or makes a guess at control. Also

few operators will adjust the excitation for best operation between parallel machines and in case of trouble the station load may be lost. If there is no low-tension parallel-bus system but instead a high-tension group-feeder unit system each unit is an entity and there is no excuse for inaccurate control. In the event of trouble the operator can directly control or isolate the unit in trouble and there is no chance of losing the station load.

c. Auxiliary Panels.—With direct-current auxiliaries a field ammeter and an armature ammeter aid operation and a recording

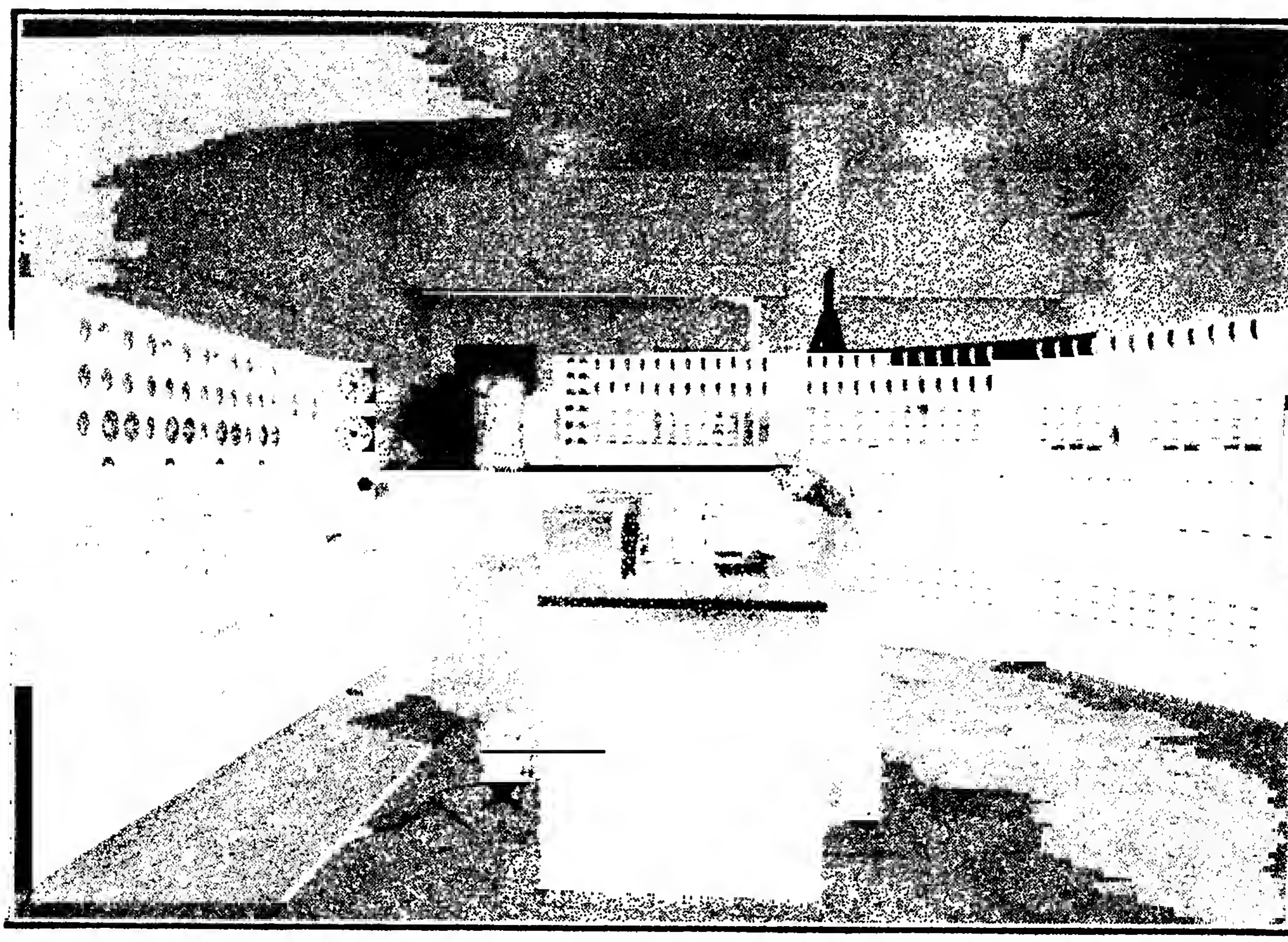

Fig. 172.—Generator and feeder control boards in one room.

meter serves to give a record of service conditions and data for determining the performance of the unit.

With alternating-current auxiliaries a recording watt-hour meter gives data for determining unit performance and ammeters give indication of loads at any instant.

Meter and Instrument Transformer Connections.—Since alternating-current circuits usually have a voltage of 2,000 volts or more, it is customary to make connections to a large part of all measuring and controlling apparatus through current and voltage transformers. This method of connecting has the added advantage that the measuring and controlling apparatus need not be built for every current and voltage capacity. Instead,

they are ordinarily made to be connected on the secondaries of current and voltage transformers, and are then made for a standard voltage (usually 100 volts) and a standard current (usually 5 amp.). The following is a partial list including the more common apparatus that is connected to current and voltage transformers:

With current transformers:
- Ammeters
- Wattmeters
- Watt-hour meters
- Power-factor meters
- Overload trip coils
- Relays
- Voltage compensators
- Voltage-regulating apparatus compensated for line drop
- Demand meters
- Transfer switches

With voltage transformers:
- Voltmeters
- Wattmeters
- Watt-hour meters
- Power-factor meters
- Over- and undervoltage releases
- Relays
- Voltage compensators
- Voltage-regulating apparatus
- Frequency meters
- Demand meters
- Reactive kilovolt-ampere meters
- Synchroscopes, and synchronizing lamps

Single-phase and Polyphase Apparatus.—The apparatus listed in the preceding paragraph may be made up of single-phase or polyphase elements, or some of the apparatus may be mounted with two or more single-phase elements in one case. For polyphase circuits, wattmeters and watt-hour meters ordinarily have two complete windings in one case connected to a single indicating pointer or recording mechanism; power-factor meters sometimes have a polyphase winding; overload relays and reverse-energy relays are sometimes made up of two or three single-phase elements in one unit. Synchroscopes have been made with polyphase windings, but for simplicity of construction and installation it is considered better practice to use a single-phase meter, even on a polyphase circuit, because all the phases will be in synchronism when one is synchronized, if the connections of the primary circuit are correct. Ammeters, voltmeters, voltage compensators, voltage-regulating apparatus, over- and undervoltage relays and frequency meters are essentially single-phase apparatus, and when used on polyphase circuits they are connected to only one phase at a time. Plugging devices are used to shift ammeters and voltmeters to the various phases and sometimes to different circuits in low-voltage or small-capacity plants. Similarly, plugging devices are used to connect a synchroscope from one

circuit to another, but the connections are in every case to the corresponding phase, so that the indications are the same as if all the circuits comprised a single-phase system. With proper connections, two-phase instruments can be applied to any kind

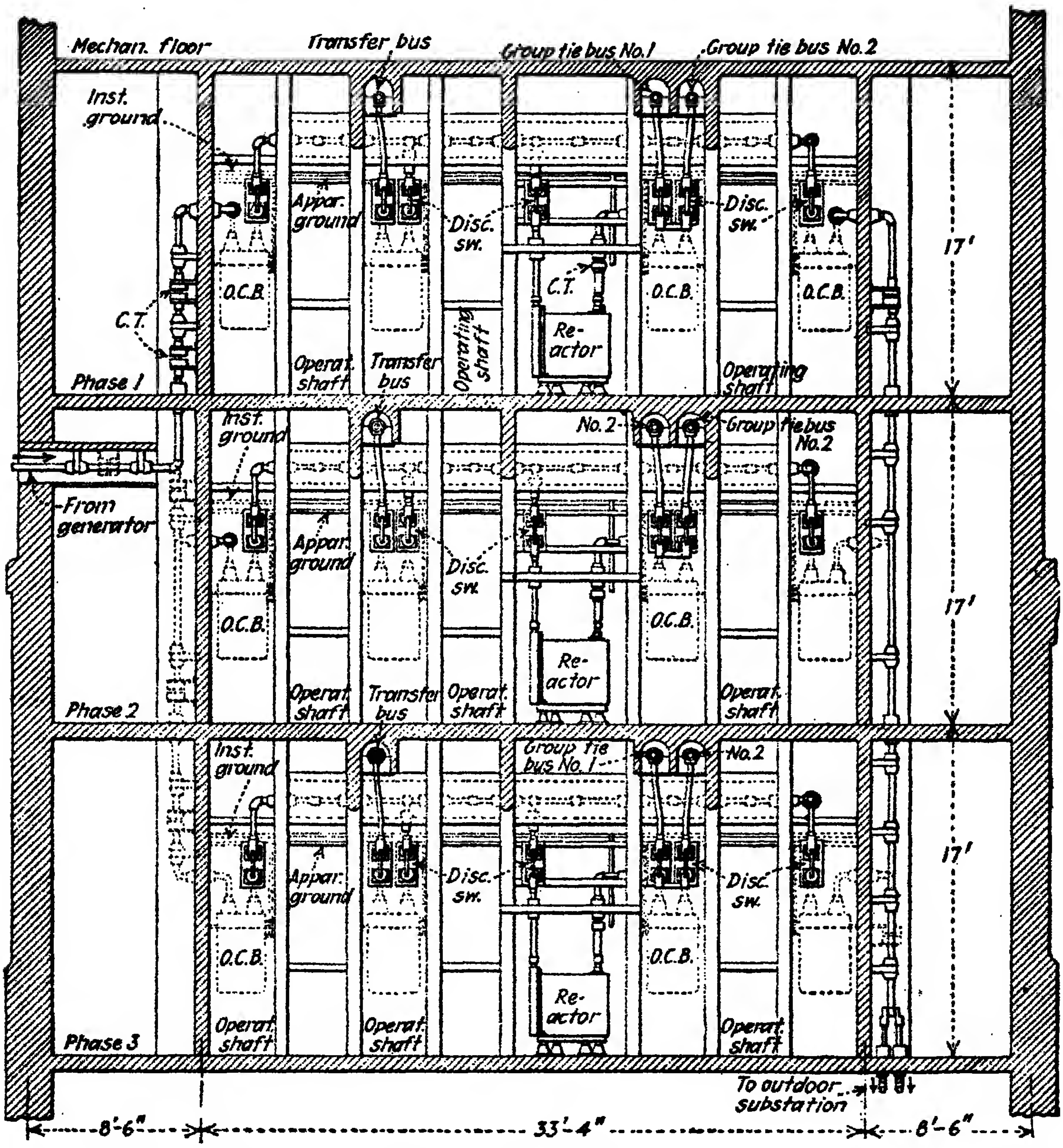

FIG. 172a.—Arrangement of buses and switches in the isolated-phase switch house of the 400,000-kw. Kearny station of the Public Service Electric Power Company.

of two- or quarter-phase circuit, and three-phase instruments can be connected to any kind of three- or six-phase circuit.

Single-phase apparatus can be used on one phase of any polyphase circuit and, similarly, polyphase apparatus that consists of two or more single-phase elements can be used on a single-phase circuit. Thus single-phase and polyphase wattmeters can be used interchangeably, with the proper connections. A poly-

phase wattmeter on a single-phase circuit may have its current windings in series or in parallel, and its voltage windings may be in series or in parallel, independent of the current windings; or only a single current winding and the corresponding voltage winding may be used. With any of these connections, the rated current and voltage of the windings must be taken into account, because if the current in the current winding or the voltage across the voltage winding far exceeds the corresponding capacity of the instrument, it may affect the accuracy of the indication, or burn out the instrument. On the other hand, if the current or

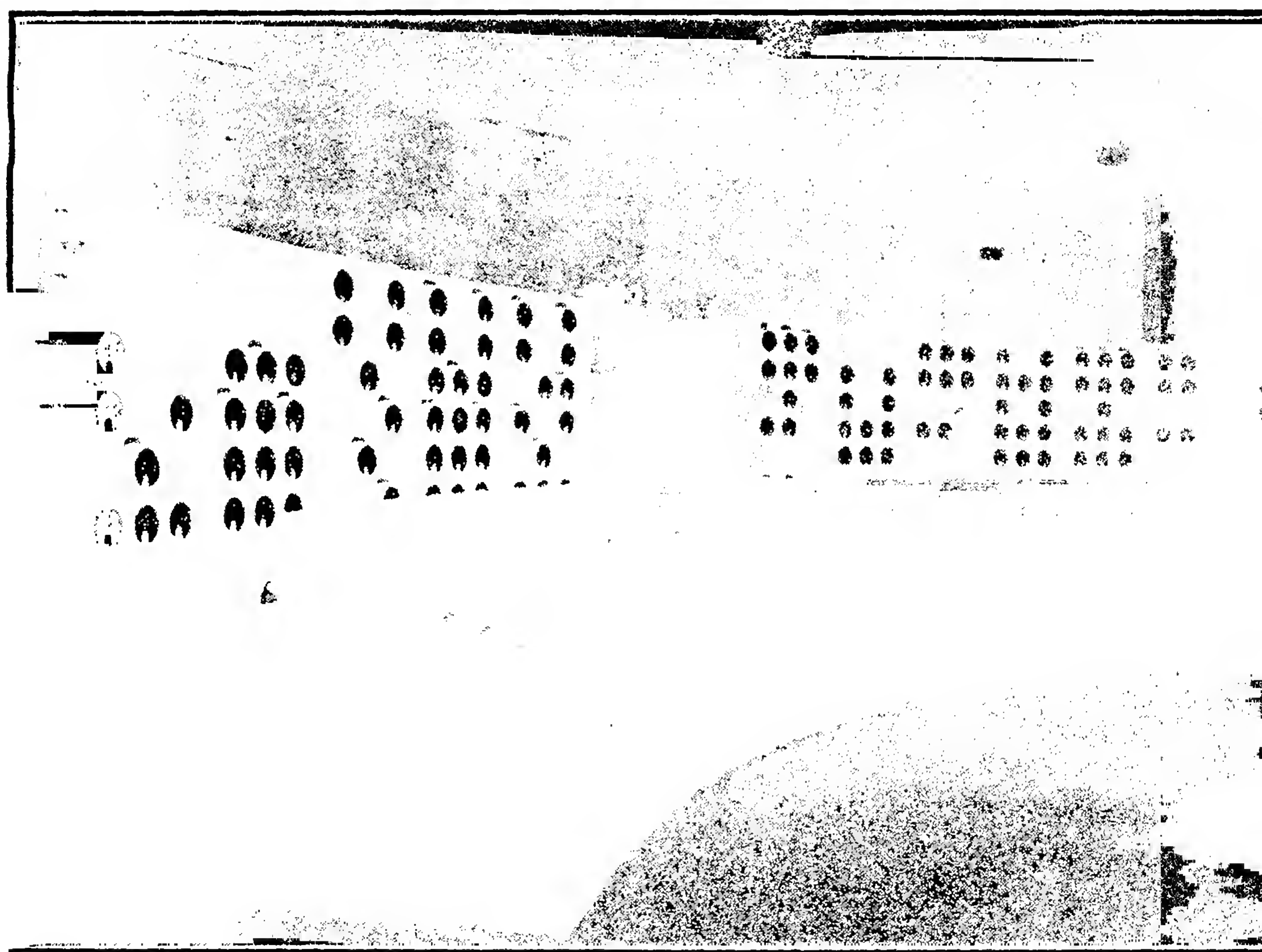

Fig. 173.—Control room in the Long Beach station of the Southern California Edison Company.

voltage is very much below that for which each element is intended, the accuracy of the indication is likely to be less than at the rated capacity.

When meters are connected to a circuit on which they were not originally intended to be used, the readings must be interpreted with due consideration for series and parallel connections of windings. If the current is divided equally between the current circuits of two meters connected in parallel, each meter receives one-half of the total current if the two circuits have the same resistance and reactance. If the current circuits are in series,

each meter receives the total current. This has nothing to do with increasing the impedance of the circuit by series connection, or decreasing it by parallel connection; the impedance of the current winding of a meter is ordinarily so low that it has practi-

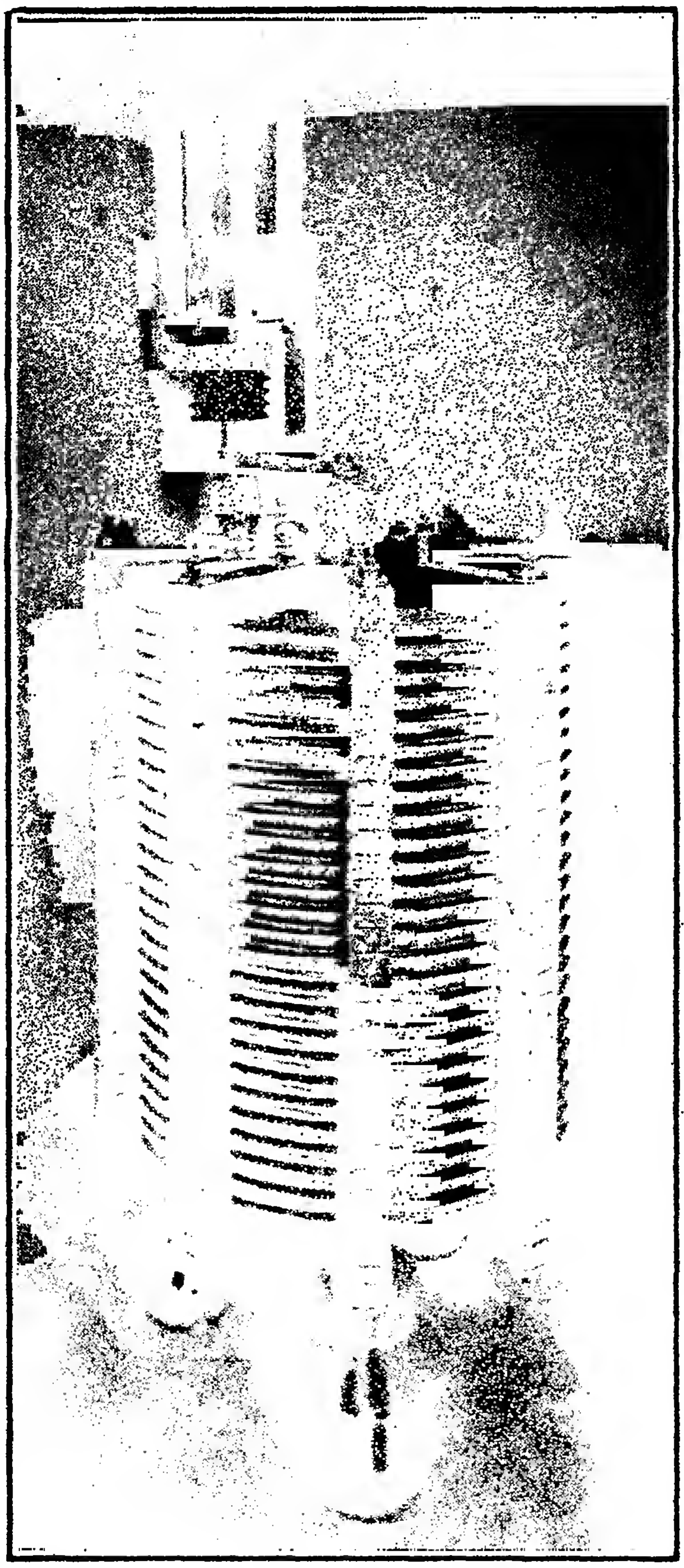

FIG. 174.—Reactor installation for a 13,200-volt feeder, the Philadelphia Electric Company.

cally no effect on the total current flowing. Other apparatus in the circuit controls the amount of current.

The statements just made do not apply to voltage circuits in the same way, for if the voltage circuits of two meters or two voltage circuits of the same meter are connected in series the

voltage across each is only one-half the line voltage if the resistances and reactances of the two are equal; but if the voltage circuits are in parallel each receives the full-line voltage. Other apparatus on the line has no effect on the current in the voltage windings unless it affects the line voltage.

Voltage-transformer Connections.—It is sometimes possible to omit one of the three voltage transformers usually used on a polyphase circuit. This results in saving not only the cost of the transformer but the space that it would occupy on the switchboard; it also saves the exciting current of the extra transformer.

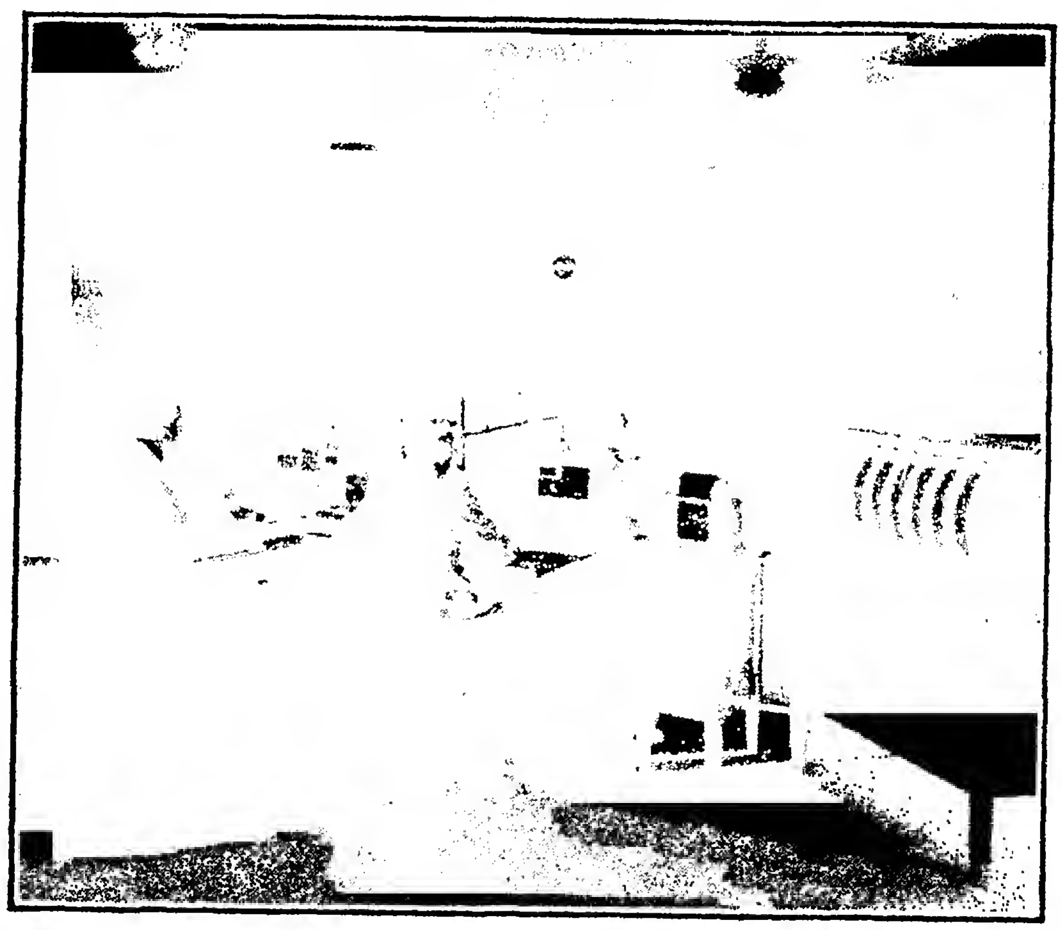

FIG. 175.—Dispatcher's office in the Philadelphia Electric Company.

In some cases this saving introduces appreciable errors in ratio and phase, but ordinarily such errors are negligible. One of the purposes of the following connections is to save transformers; but there are other advantages and disadvantages that will be mentioned, along with the description of each connection. Where power transformers have secondary connections different from the primary, the voltage transformers may have corresponding connections, so that when the voltage transformer primary corresponds to one side of the power transformer, the secondary corresponds to the other side. For example, a bank of power transformers have one side Y-connected to a 66,000-volt line, and the other side delta-connected to a 2,300-volt line. If the voltage transformer is delta-connected to the 2,300-volt line and

its secondary is Y-connected, the secondary voltages are made to correspond to the phases of the 66,000-volt line, without the high cost of a 66,000-volt transformer. It must be remembered, however, that an error is introduced, due to imperfect regulation of the power transformer under varying loads.

Delta connection has no advantage over the open delta, except for better regulation. Usually the regulation is amply good, so that the delta is hardly ever used in practice. Sometimes it is desired to obtain not only the three voltages between lines, but also the voltages in phase with the voltages to neutral—all from

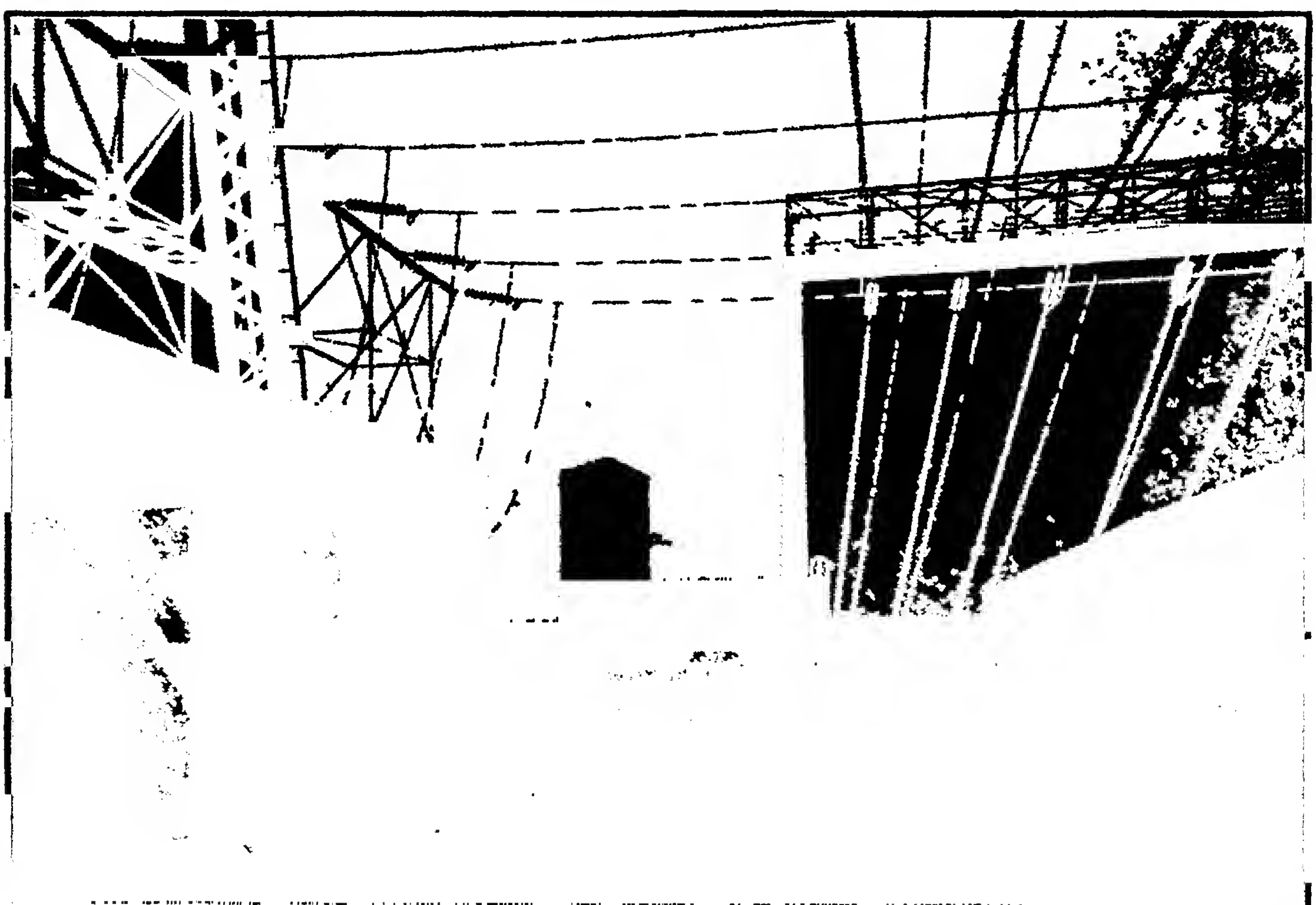

FIG. 176.—Unique way of taking 66,000-volt lines from the interior of Colfax station of the Duquesne Light Company.

the same three transformers. This can be accomplished in several ways with different connections. With delta-connected transformers it is accomplished by bringing out 50 per cent taps on the transformer secondaries. The second set of voltages is obtained by connecting from each corner of the delta to the middle of the opposite side. They are 86.6 per cent of the line voltage, if the three-line voltages are equal.

V or open-delta connection is the one almost universally used on three-phase three-wire circuits. In practice the voltages to neutral are rarely measured, and the voltages between lines are obtained with as great accuracy as is ordinarily required. While

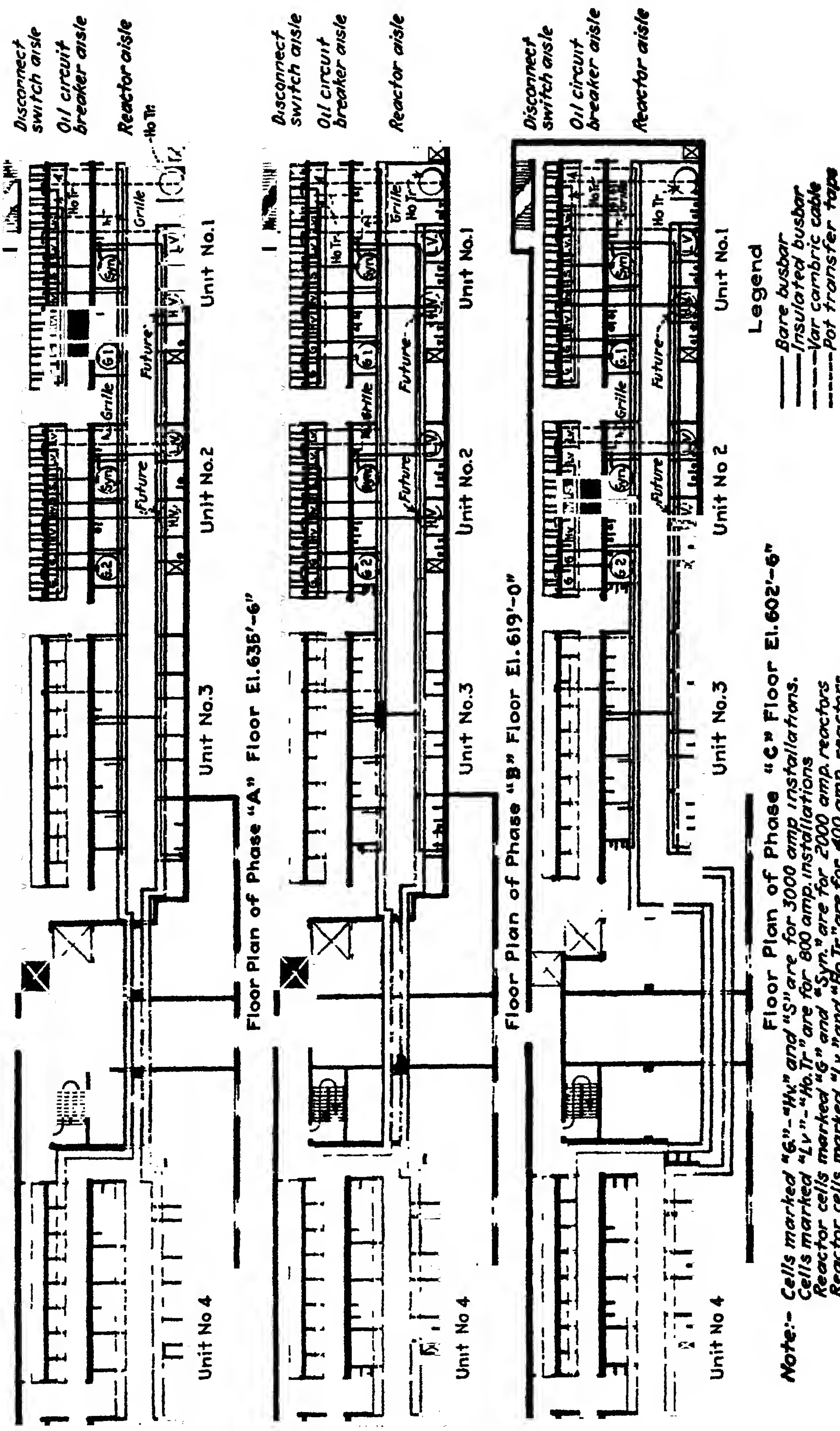

FIG. 177.—Floor plan of isolated-phase switch house in Avon station of the Cleveland Electric Illuminating Company.

the regulation is not quite so good as with the delta connection, it is good enough because the load on a voltage transformer is constant and usually small. Two voltages in phase with voltages to neutral can be obtained as with the delta connection, by bringing out 50 per cent taps and connecting from the outer end of one transformer to the middle of the other.

Y-connection is used on three-phase four-wire circuits where the three voltages to the neutral wire are to be measured accurately. Such a connection is not satisfactory on a three-wire ungrounded system, unless the three transformers take the same exciting currents when their voltages are equal. If any one of the three exciting currents is different, the three voltages to neutral will not be accurate.

Y-to-delta- or delta-to-Y-connected shifts the phases by 30 deg., if the voltages are balanced. The *Y*-to-delta connection makes the secondary voltage $1/\sqrt{3}$ of what it would be with Y to Y or delta to delta. The delta to Y makes the secondary voltage $\sqrt{3}$ times what it would be with Y to Y or delta to delta. Such a connection may be used in the manner mentioned above to correspond to the difference between the high- and low-tension sides of a power transformer.

V-connection to neutral, or open Y-connection is used on three-phase four-wire circuits where only two voltages to neutral are required. This is used with a polyphase wattmeter and some other instruments. The two secondary voltages are 30 deg. from the voltages with the open-delta connection. If the secondary connections of one transformer are reversed the resultant voltage across the two secondaries is in phase with the primary voltage from the third line to neutral (assuming balanced voltage).

T-connection is used on three-phase circuits where it is desired to bring out an artificial neutral. It can also be used for changing from two to three phase, or from three to two phase, to correspond to the connections of power transformers.

Reversed V-connection is the same as the V-connection, with one of the secondaries reversed. Two of the voltages are the same as with the V-connection, and the third is the geometric difference, instead of the geometric sum of the two. If the voltages of the line are balanced, the third secondary voltage is in phase with the voltage to neutral, from the line that is common to the other two voltages. That is, if one transformer is across *AB* and one across *BC* the third voltage is in phase with *B* to

neutral voltage. It is $\sqrt{3}$ times the secondary voltage of either transformer, or three times the voltage from any corner of the secondary delta to the secondary neutral.

Current-transformer Connections.—The number of current transformers can frequently be reduced by making connections to the best advantage. This and other considerations make it important to see that the best arrangement is utilized for each individual case.

Delta Connection.—The current from each lead is from the *incoming* end of one transformer and the *outgoing* end of another. If the load is balanced, the total current is 30 deg. out of phase with that in one line, and $\sqrt{3}$ times the line current. This connection may be used (1) with a polyphase wattmeter on a three-phase four-wire circuit; (2) where current transformers are connected into the primary circuit inside a delta load or inside the delta of a bank of transformers, to determine the total current in the line; and (3) in several other cases that need not be enumerated here.

Y-connection is used on three-phase four-wire circuits where it is required to measure the current in each of the primary lines. The current in the neutral can be measured also, as it is proportional to the current returning in the common line of the three transformers.

Open-delta or *V-connection* has the common line connected to the incoming end of one transformer, and the outgoing end of the other. As with the delta connection, with a balanced load, the current in the common line of the secondary is $\sqrt{3}$ times the current in either of the other secondary lines, and 30 deg. out of phase with either one. It is, therefore, in phase with the voltage between the two lines in which the transformers are connected. This fact is sometimes important where single-phase apparatus is to be connected to a three-phase circuit to indicate the condition of the entire circuit. A single-phase wattmeter with its current winding in the common line and with its voltage winding connected between the two lines having current transformers will indicate the total power correctly at all power factors if the load is balanced. A single-phase power-factor meter with the same connections will indicate power factor correctly on balanced load. A voltage compensator with its current element in the common line will make compensation for line drop in the two lines having current transformers.

Reversed V-connection is the most common connection of current transformers. The currents in the three secondaries are proportional to the three primary currents, in case of a three-wire circuit. With such a circuit this connection is suitable for one or three ammeters or ammeter receptacles, two or three single-phase or one polyphase wattmeter, a polyphase power-factor meter and other apparatus. It is suitable for use with two overload relays or other overload protective apparatus if the Z-connection is not considered necessary.

Z-connection is the same as the delta connection with the leads to one of the transformers reversed. The reversed transformer may be any one of the three. This connection is used for protecting circuits against overload where there is danger of short circuit due to grounding any one of the three lines of the primary. It is true in this case as with the reversed V-connection that if corresponding ends of the secondaries of transformers in two lines are connected to a common return the current in the return wire is proportional to the primary current in the third line. Thus if the outgoing ends of transformers on A and B are connected to the common line the resultant secondary current is proportional to the current in C provided there is no ground. Similarly, the common line connecting to corresponding ends of B and C carries a current proportional to the primary current in A. If one single-phase relay is connected to the common line to transformers A and B, and one to the common line for transformers B and C they will offer the same protection as if there were only two transformers with a reversed V-connection, *if there is no ground.* Instead of this connection the Y-connection is sometimes used with three relays. The principal disadvantage of this is in the cost of providing the additional relay. There is no advantage in using three Z-connected transformers instead of two reversed V-connected, unless there is danger of ground; but if any one of the lines is grounded and carries an excessive current, it will operate one or both of the relays with the Z-connection, whereas only two of the lines are thus protected by the reversed V-connection.

Meter and Relays Connected to Transformers.—One of the most common ways of connecting meters and relays to a three-phase circuit is as follows: The two current transformers for the meters have a reversed V-connection. A polyphase wattmeter or watt-hour meter is permanently connected to the current transformers, and ammeters are arranged to read the current in

each of the phases or, by means of a plug and receptacles, one ammeter may be used. The voltage transformers are V-connected, and the wattmeter and reverse-energy relays are permanently connected to them. A voltmeter is connected to a voltmeter receptacle, so that it can be plugged across any two lines. Two overload or reverse-energy relays are connected to a set of three Z-connected current transformers. It would be possible to use the same current transformers for the meters and the relays, but the impedance of the relays is usually so high that under some conditions it would introduce serious errors in the meter indications if the meters were on the same current transformers. The relay contacts are connected across the direct-current control circuit in series with the circuit-breaker trip coil.

The connections that are used in any case must depend on the specific requirements. The following are cases of modifying the foregoing connections:

1. If a rather large error is allowable in meter indication, the meters can be connected to the same transformers that are used with the relays.

2. If there is no danger from grounding, it is unnecessary to add the third of the Z-connected transformers for the relays.

3. If there is no direct-current control circuit available, the relays and circuit-breaker trip coil may be constructed to take care of this condition; the trip coils should then be wound with as low impedance as possible, to operate from the secondary current of the current transformers. The relay is made so that in case of overload its contact is opened instead of closed. The current transformers are connected so that with normal operation their currents flow through the relay coils, through the relay contacts and back to the current transformers. There are two circuit-breaker trip coils instead of one, and each is connected in parallel with the contact of one of the relays, so that, in case of overload, when the relay contact is opened the current is forced through the coil.

4. Three ammeters may be required for convenience in reading, instead of one ammeter and three receptacles.

5. The voltmeter receptacle may be connected so that when the plug is in the left-hand position the voltmeter indicates the voltage on one side of the circuit breaker, and in the right-hand position it indicates the voltage on the other side. These volt-

ages are usually on different phases, so that when the breaker is closed the voltmeter will indicate any of the three-phase voltages.

6. An additional voltmeter may be connected to the other side of the circuit breaker instead of plugging one voltmeter first on one side and then on the other. For example, if the circuit under consideration connects a generator to a three-phase bus (and there are several such generator circuits) one voltmeter may be connected to plug across one phase of any of the generators.

7. A power-factor meter or reactive power meter may be added in series with either set of transformers.

8. If a three-phase circuit has a neutral wire, or the neutral is grounded without resistance, the wattmeter current circuits should be connected to delta-connected current transformers, and the voltage transformers should be connected in V to neutral. This connection takes account of current that might otherwise flow in the *B* line and return in the neutral.

9. A single-phase three-wire circuit may have connections almost the same. The current transformers for the relays would not be Z-connected in this case.

10. On a single-phase three-wire circuit a polyphase wattmeter would usually be replaced by a single phase, and the current transformer connections would be changed. Either a single transformer with two primaries and one secondary would be used, or the two transformers would have their connections modified so that a current on either outside line would have the same effect on the wattmeter. When the ammeter is inserted in the common line it indicates the current in the neutral wire. If one of the transformers were reversed so that a single-phase wattmeter would totalize the power, an ammeter in the common line would totalize the current.

Special Connections.—When using reverse-energy relays on delta or Y ungrounded circuits a three-pole or polyphase induction type relay can be used with two current and two potential transformers. The third element in the relay carries the resultant current and the open-delta voltage and compensates for phase unbalancing and is somewhat better than three single-phase relays. But for grounded systems this connection does not afford complete protection.

Interconnection or interlocking of relays of the pilot-wire, differential or reverse-energy types is a specific problem for each installation. High-tension series overload relays, overvoltage

relays, low-voltage relays, underload relays, control relays, signal relays are other special relay applications to specific conditions.

Energy for Operating Switchboard Equipment.—The usual meter-type current transformer is designed for a rating of 50 volt-amp. with compensation for loads from 25 to 40 amp., so that the ratio error in this range is small. The meter-type potential transformer is rated at 20 volt-amp. with compensation for loads between 15 and 30 volt-amp. As many switchboard meters have been introduced and used, it becomes necessary to use care in using instruments with standard transformers to the extent that they are overloaded with consequent ratio and phase-angle errors. The following table[1] shows some representative switchboard meters and the data concerning their use with instrument transformers:

TABLE XXXVIII.—NORMAL RATINGS AND DUTY OF SWITCHBOARD EQUIPMENT

Instrument	Type	Current				Voltage			
		25 cycles		60 cycles		25 cycles		60 cycles	
		EI	*W*	*EI*	*W*	*EI*	*W*	*EI*	*W*
Ammeter	Induction	6.3	6	3.1	3				
Ammeter	Solenoid	8.0	5	8.0	5				
Graph. ammeter	Relay	10.0	6	10.0	6				
Graph. ammeter	Solenoid	16.0	5	16.0	5				
Voltmeter	Induction	....	....	....	....	10.9	9.7	10.9	9.7
Graph. voltmeter	Relay	....	....	....	....	14.5	15.5	14.5	14.5
Graph. voltmeter	Solenoid	....	....	....	....	31.7	28.0	31.7	28.0
Wattmeter	Switchboard	4.0	4	4.0	4	7.6	6.65	7.6	6.65
Graph. wattmeter	Relay	3.5	3.5	3.5	3.5	9.7	9.7	9.7	9.7
Graph. WM. control circuit	Relay	....	....	....	....	36.0	24.0	36.0	24.0
Watt-hour meter	Switchboard	1.5	0.7	1.5	0.7	12.3	1.6	12.3	1.6
Power-factor meter	Iron vane	1.5	1.5	1.5	1.5	13.3	12.1	13.3	12.1
Graph. power-factor meter	Relay	3.5	3.5	3.5	3.5	13.3	12.1	13.3	12.1
Reactive-factor meter	Same as power-factor meter								
Graph. reactive-factor meter	Same as graph. power-factor meter								
Frequency meter	Induction	....	....	....	....	24.0	18.0	24.0	18.0
Graph. frequency meter	Relay	....	....	....	....	42.0	30.0	42.0	30.0
Overload relay	Induction	16.0	9.6	17.0	8.5				
Reverse-power relay	Induction	18.0	11.0	17.0	10.0	14.5	2.8	20.0	2.5
Circuit-breaker trip	Light-pull	18.8	....	42.5					
Circuit-breaker trip	Heavy-pull	32.0	....	65.0					
Circuit-breaker low-voltage coil	....	....	....	....	....	....	....	8.4	27.5
Direct trip relay	....	20.0	10.0	10.0					
Direct trip relay	....	20.0	10.0	35.0	17.5				
Voltage-regulating solenoid	....	....	....	....	....	60.0	48.0	60.0	48.0
Low-voltage relay	Induction	....	....	....	....	13.3	12.1	13.3	12.1

[1] *Electric Journal*, January, 1920.

Relays.—In its broadest sense a relay is an auxiliary device which, on the occurrence of some specified predetermined condition in an electrical circuit, will operate and transmit its action to another independent piece of apparatus. The modern idea of relays is to use a relay to secure continuity of service, to protect against loss of synchronous load and, by selective time elements, etc., to disconnect only such positions of circuits as are in trouble. In order to determine the settings for the relays in a system, the following general data should be known:

1. The instantaneous short circuit in each conductor.
2. The sustained short-circuit current.
3. The time in changing from circuit 1 to 2.
4. The time required for the various automatic breakers to open after current is applied to their coils.
5. The safe circuit-opening capacities of the various breakers.
6. The time characteristics of the various relays.
7. The probability and amount of reversal of energy flow in the case of parallel circuits.

The time element of relays is of more importance than the current setting, as in short circuit the current setting may be exceeded several hundred per cent.

In its mechanical make-up a relay consists of (1) a coil or a system of coils connected in series or parallel to the circuit which it controls; or in series or in parallel with the secondaries of current or voltage transformers; (2) a contact device; (3) a secondary operating circuit.

Under equal conditions a circuit-closing device is better than a circuit-opening because it makes contact with the whole force of the moving part while the circuit-opening relay, particularly if the opening is slow, may give trouble due to pitting and arcing at contacts.

In general, the overload alternating-current relays may be divided into three characteristic divisions:

1. According to the contact device which, when responding to the impulses of the system, makes or breaks contact.
2. According to the time elapsing between the occurrence of the disturbance and the operation of the contact device.
3. According to the nature of the disturbance, its magnitude or the direction of energy flow.

Relays may be instantaneous, definite-time limit and inverse-time limit. With instantaneous relays the contact device will

operate immediately when the disturbance occurs. With inverse-time-limit relays there will be a delay in the relay operation inversely proportional to the magnitude of the disturbance. With definite-time-limit relays the operation occurs only after a definite time has elapsed.

Practically all modern relays introduce a magnetic drag effect to secure the time element and in principle are built similar to induction-type watt-hour meters. Some thermal relays are used but they play but little part in power plant installations.

Most power plant switchboard relays are contact making and the contact device utilizes a direct-current circuit to carry out the protective operations required in time of trouble. A very large number of relays are available and the choice depends on the protective system selected. A trend in relay design is to build them so they indicate they are energized and ready for work at all times because correct relay operation is the one big essential to good service in modern stations.

The relays in a power station are located on switchboard panels in most cases and the control wiring for relays becomes as complex as that required for metering equipment.

INDEX